EFFECT OF IAA ON BARI MUNGBEAN-6 UNDER WATER LOGGING CONDITION AT POD MATURITY STAGE

MAHAMUD JUBAID HASAN RASEL

DEPARTMENT OF AGRONOMY

SHER-E-BANGLA AGRICULTURAL UNIVERSITY

DHAKA-1207

JUNE, 2022

EFFECT OF IAA ON BARI MUNGBEAN-6 UNDER WATER LOGGING CONDITION AT POD MATURITY STAGE

BY

MAHAMUD JUBAID HASAN RASEL

REGISTRATION NO. 15-06585
E-mail: raseldr143@gmail.com
Mobile: 01952872107

A Thesis

Submitted to the Faculty of Agriculture,
Sher-e-Bangla Agricultural University, Dhaka
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE (MS)
IN
AGRONOMY

SEMESTER: JANUARY-JUNE, 2022

APPROVED BY:

....	....
Prof. Dr. Md. Shahidul Islam	**Dr. H. M. M. Tariq Hossain**
Supervisor	**Co-Supervisor**

....
Prof. Dr. Md. Abdullahil Baque

Chairman

Department of Agronomy

DEPARTMENT OF AGRONOMY
Sher-e-Bangla Agricultural University (SAU)
Sher-e-Bangla Nagar, Dhaka-1207

Ref. No.: Date:

CERTIFICATE

This is to certify that thesis entitled ***"EFFECT OF IAA ON BARI MUNGBEAN-6 UNDER WATER LOGGING CONDITION AT POD MATURITY STAGE"*** *submitted to the* ***Faculty of Agriculture,*** *Sher-e-Bangla Agricultural University (SAU), Dhaka in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE (MS) in AGRONOMY,*** *embodies the result of a piece of bona fide research work carried out by* ***MAHAMUD JUBAID HASAN RASEL*** *Registration No. 15-06585 under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that any help or source of information, received during the course of this investigation has been duly acknowledged and style of this thesis have been approved and recommended for submission.

Dated: June, 2022
Place: Dhaka, Bangladesh

Prof. Dr. Md. Shahidul Islam
Department of Agronomy
Sher-e-Bangla Agricultural University
Supervisor

DEDICATED
TO
MY BELOVED
PARENTS

ACKNOWLEDGEMENTS

At first, the author takes the opportunity to express his deepest sense of gratefulness to Almighty Allah who enables the author to complete his research work for the degree of Master of Science (MS) in Agronomy.

The author really does not have adequate words to express his heartfelt sense of gratification, ever indebtedness and sincere appreciation to his benevolent teacher and research supervisor **Prof. Dr. Md. Shahidul Islam,** Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka-1207, for his constant help, scholastic guidance, planning experiment, valuable suggestions, timely and solitary instructive criticism for successful completion of the research work as well as preparation of this thesis.

It is a great pleasure for the author to express his sincere appreciation, profound sense, respect and immense indebtedness to his respected co-supervisor, **Prof. Dr. H. M. M. Tariq Hossain,** Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka-1207, for providing him with all possible help during the period of research work and preparation of the thesis.

The author is highly grateful to and **Prof. Dr. Md. Abdullahil Baque,** Chairman, Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka for his valuable advice, constructive criticism and factual comments in upgrading the research work and this document.

The author would like to express his deepest respect and boundless gratitude to all the respected teachers of the Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka-1207 for their sympathetic co-operation and inspiration throughout the course of this study and research work.

Cordial thanks are also due to all laboratory staff and field workers of SAU farm for their co-operation to complete his research work in the field.

The author deeply acknowledges the profound dedication to his beloved parents and brother for their moral support, steadfast encouragement and continuous prayer in all phases of academic pursuit from the beginning to the completion of study successfully.

The Author

EFFECT OF IAA ON BARI MUNGBEAN-6 UNDER WATER LOGGING CONDITION AT POD MATURITY STAGE

BY
MAHAMUD JUBAID HASAN RASEL

ABSTRACT

A pot experiment was conducted at the Sher-e-Bangla Agricultural University, Dhaka 1207, Bangladesh, during April 2022 to July 2022 to find out the effect of Indole-3-acetic acid (IAA) on mugnbean at pod maturity stage under water logged condition. The experiment comprised of two factors, where factor A refers two level of water logging (W_0 = No excess water stress; W_e = Excess water stress at pod maturity stage) and factor B comprised of 5 level of IAA (I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and 2 days after stress imposition). There were 10 treatment combinations and experiment was setup in Completely Randomized Design (CRD) with four replications. The study revealed that waterlogging showed remarkable decrease of plant height in all growth stage, branch number plant^{-1}, above ground fresh weight plant^{-1}, above ground dry weight plant^{-1}, pod length, number of pods plant^{-1}, SPAD value, relative water content, 1000 seeds weight and yield plant^{-1}. Application IAA @ 200 ppm produced the tallest plant at harvest (50.60 cm); earliest maturity (56.63 days); maximum above ground fresh weight and dry weight of plant^{-1} (10.52 g and 8.63 g, respectively), maximum pod number per plant (13.88); highest SPAD and RWC value (50.43 and 72.07, respectively), 1000 seeds weight (39.17 g) and yield plant^{-1} (12.92 g). In combined effect, the application of IAA @ 200 ppm significantly increases plant height, branch number, early flowering and maturity, increase pod number, pod length, SPAD value, RWC value, 1000 seeds weight and yield per plant in both no and excess water stress conditions. So, water logged mungbean plant at maturity stage may be given IAA @ 200 ppm for minimize the detrimental effect of excess water stress for optimum crop production.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviation	**Full meaning**
AEZ	Agro-Ecological Zone
Agric.	Agriculture
Agril.	Agricultural
BBS	Bangladesh Bureau of Statistics
Cm	Centimeter
CV	Co-efficient of variation
^oC	Degree Celsius
df	Degrees of freedom
DAS	Days After Sowing
et al.	And others
FAO	Food and Agriculture Organization
G	Gram
ha	Hectare
J.	Journal
kg	Kilogram
LSD	Least Significant Difference
mg	Milligram
MoP	Muriate of Potash
CRD	Completely Randomized Design
SAU	Sher-e-Bangla Agricultural University
TSP	Triple Superphosphate

CHAPTER I

INTRODUCTION

Mungbean (*Vigna radiata* (L.) Wilczek) is short-durational (sub) tropical grain legumes and is important due to their valuable seed nutritional composition for the human diet and income for growers (Somta and Srinives, 2007). The crops are mainly grown in Asia with some cultivated in Africa and Oceania. Globally, mungbean covers more than 7.3 million ha with an annual global production of 5.3 million tons (Kyu *et al.*, 2021). It is an important pulse crop of Bangladesh, which contains high graded vegetable proteins and satisfactory level of minerals and vitamins. Forage contains 12-18% protein but seeds contain 22-28% protein, 60-65% carbohydrates, 1-1.5% fats, 3.5-4.5% ash (El-Karamany, 2006). This pulse plays a significant role as supplement of low protein diet of poor people in Bangladesh but its production and acreage are declining day by day with an average yield of 0.88 ton ha^{-1} (BBS, 2022). After 1970s, the production area of pulses is in decreasing trend in Asia due to increasing cultivation of cereals and vegetable crops (FAO, 2011; Munir *et al.,* 2012). Among the pulse area, only 8.10% lands in Bangladesh are used for the cultivation of mungbean (Mondal *et al.,* 2013). According to World Health Organization (WHO), per capita per day requirement of pulse is 45 g. However, in Bangladesh, only 12g pulse is available per capita per day. About 6.01 million tons of pulse is required to meet the present per capita requirement of our country. However, its large-scale adoption is constrained by low yield potential. Various biotic and abiotic factors are responsible for low yields of mungbean (Chotechuen, 1996). Among the abiotic stresses, excess moisture or soil flooding stands prominent.

Mungbean cannot withstand waterlogging, particularly during the early stages of growth (Singh and Singh, 2011). Waterlogging can reduce the gas exchange between soil and air, resulting in 10,000-fold reduction in gas diffusion in water. Under submergence conditions, O_2 in the soil rapidly decrease and the soil can become hypoxic or anoxic within few hours (Bailey-Serres and Voesenek, 2008). Waterlogging lead to soil nutrient deficiencies or toxicities, affects plant growth, and results in roots death followed by damage entire plant (Tian *et al.,* 2021; Wollmer *et al.,* 2019). The waterlogging tolerant plant species have developed diverse and complex strategies to survive under waterlogging condition, including morphological, anatomical, and physiological adaptations as well as hormonal interactions (Pan *et al.,* 2021). During waterlogging, numerous morphological changes occurred, such as the formation and development of adventitious roots (ARs). These types of roots are different from lateral or primary roots, as based on a general definition that ARs arise from non-root tissues (Steffens and Rasmussen, 2016). ARs can be form from hypocotyl pericycle cells, phloem or xylem parenchyma cells, young secondary phloem cells, or interfascicular cambium cells close to the phloem cells and facilitate gas transport and water and nutrient uptake during water stress condition (Bellini *et al.,* 2014). Plant hormones, such as abscisic acid (ABA) and auxin (IAA), and photosynthesis are involved in the regulation and promotion of adventitious roots, which is a common adaptive response of plants to waterlogging. It has been well established the crucial roles of IAA in plant growth and ARs formation under stress.

Plant growth regulators (PGRs) are known to influence plant growth and development at very low concentrations. Moreover, the response of plant to PGRs may vary with species, varieties, environmental conditions, physiological and nutritional status, stage of development and endogenous hormonal balance (Naeem *et al.,* 2004) delays senescence (Shah, 2007). Plants have the ability to store excessive amounts of exogenously supplied hormones in the form of reversible conjugates which release active hormone when the plants need them during the growth period (Davies, 2004). Amanullah *et al.* (2010) mentioned that plant growth substances are known to enhance the source-sink relationship and stimulate the translocation of photo-assimilates to sink thereby helping in effective flower formation, fruit and seed development and ultimately enhancing the productivity of crops. Various plant growth regulators which regulate growth under normal or stress conditions are auxins. Generally, auxins are the best hormones for use because they are non-toxic to plants over a wide range of concentration and effective in promoting root system of large number of plant species. Auxins might regulate cell elongation, cell division, tissue swelling, formation of adventitious roots, callus initiation, induction of embryogenesis and promoting cell wall loosening at very low concentrations (Taiz and Zeiger, 2006). The principal auxin in plants is indole-3-acetic acid (IAA) that is produced mainly in the shoot apex bud and young leaves of plants. Other meristematic tissues, flowers, fruits and young seeds have also been shown to be sites of this hormone production (Sadak *et al.*, 2013). Auxin plays a key role that mediates its function in flowers and fruits through an integrated process of biosynthesis, transport, and signaling, as well as interaction with other hormonal pathways. Optimum supply of required nutrient to the reproductive organs from the leaf could nourish it and enhance its life. IAA, a naturally synthesized growth hormone, plays a very important role to enhance crop growth and development, which could increase the availability of food to the growing plant when required. Auxin regulates many physiological processes against flower and pod dropping. Plant hormones ethylene, abscisic acid and jasmonates induce senescence; and auxin, cytokinin and gibberellins play a role in its suppression (Lim *et al.,* 2003). Artificial applied auxin could increase root and shoot growth which could help to harvest, water, nutrients etc. to produce more food by individual plant. Therefore, artificially applied auxin might have a positive effect to reduce flower and pod dropping and increasing yield under water logging condition (Aktar, 2015).

Considering the above facts, the experiment has been undertaken with the following objectives:

- To study the effect of different levels of IAA on the growth and yield of mungbean variety;
- To analyze the morphological and physiological changes of mungbean due to waterlogging condition;
- To investigate the interaction effect of IAA and waterlogging on the growth and yield of mungbean.

CHAPTER II

REVIEW OF LITERATURE

Now-a-days the world agriculture is counteracting multiple challenges like: a) 70% more food for an additional 2.3 billion people by 2050 b) Struggle with poverty and hunger and c) adaption towards climate change. Legumes are economically important crops and rich source of nutritious food (for human), feed (for livestock), agronomic matter (for soil), organic matter (for soil) and raw materials (for industries). Additionally, legumes have symbiotic association with the nitrogen fixing rhizobium present in the nodules hence; the plants do not require external nitrogen sources such as nitrogen fertilizers. Therefore, it necessitates to enhance the productivity of the agronomical valuable food grain legumes to meet the nutritious food demand for ever increasing population by exploiting scarce natural resources more efficiently. Considering the studies, the review of literature is presented under the following heads:

2.1 Effect of waterlogging on mugnbean and other crops

2.1.1 Effect on growth

Anee *et al.* (2019) conducted an experiment on sesame plants (*Sesamum indicum* L. cv. BARI Til-4) to investigated the effects of waterlogging where treatments were waterlogging for 2, 4, 6, and 8 days during the vegetative stage. The reduction of relative water content and photosynthetic pigment with waterlogging duration increased. The lower reduction of RWC was observed 2 days waterlogged and the highest reduction was observed 8 days waterlogged (75%) where control was 90% RWC. In stressed plants the content of chlorophyll (Chl) and carotenoid also decreased over time.

Amin *et al.* (2016) carried out a field experiment with some selected mungbean genotypes viz. IPSA-13, VC-6173A, BU mug 2, BARI Mung-5 and IPSA-12 to observe the effect of 4-days flooding on their growth and yield of mungbean under field conditions at Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh during September to November, 2011 maintaining 3-5 cm standing water at 24 days after emergence. They found that days to flowering and maturity delayed in flooded plants over control depending on the genotypes. Flooding significantly reduced

Total day matters (TDM), number of pods per plant, seed size and seed yield of the Mungbean genotypes over control. Considering higher seed yield, larger seed size and less yield reduction relative to control VC-6173A, BU mug 2 and IPSA-13 were found tolerant to soil flooding condition.

Prasanna and Rao (2014) showed the remarkable variation on growth measuring factors of green gram as a result of waterlogging. Due to waterlogging during the life cycle shoot length, leaves number, flower number and total biomass were significantly decreased. The effect of waterlogging for 4 days was more serious compared to waterlogging treatment for 2 days over the unstress plant. In waterlogged plants, shoot length, leaves number and total biomass were reduced by 30–34% compared to control.

After conducting an experiment Sairam (2013) reported that, mungbeans (*Phaseolus aureu*s Roxb.) were grown for 2 weeks in gravel-vermiculite soilless mix in a growth chamber and subjected to a 1-week waterlogging period followed by a 1-week recovery period. Sequential harvests were made to determine the time course of effects of waterlogging and subsequent recovery on growth parameters by techniques of growth analysis. Root dry matter was the first to be affected, along with an increase in leaf dry matter and specific leaf weight. After a 1-week waterlogging period, specific leaf weight had more than doubled in the stressed plants. Leaf area declined in relation to the control plants as did the ratio of root dry matter to shoot dry matter. During the recovery period there was an increase in the dry matter allocation to the roots relative to the shoot. Specific leaf weight fell to control levels although the rate of leaf area elaboration did not increase during this time, suggesting a redistribution of stored assimilates from the leaves. Net assimilation rate increased during the waterlogging period, probably due to a restriction in root metabolism and reduced translocation out of the leaf rather than to an increase in photosynthesis. Net assimilation rate of waterlogged plants was severely reduced compared with control plants during the recovery period. Both relative growth rate and leaf area duration declined during the waterlogging period and declined further subsequent to the waterlogging treatment. The results illustrate the interrelationships between roots and shoot carbon budgets in mung bean during response to the stress of waterlogging.

Tolerant and sensitive type of mung bean (*Vigna radiata*) genotypes including T 44 and MH–96–1 (tolerant) and Pusa Baisakhi and MH–1K–24 (sensitive) were experimented by Kumar *et al.* (2013) for waterlogging induced changes. Thirty-day old plants were waterlogged for 3, 6 and 9 days. They observed that waterlogging reduced the leaf surface, the growth rate of crops, development of roots and nodulation capacity in all plants where tolerant plants showed lower reduction of these parameters.

2.1.2 Effect on plant physiology and metabolism

Tian *et al*. (2019a) showed that the most important effects of photosynthetic enzymes occurred at the seedling, jointing and tasseling phase. The activity of the photosynthetic enzyme was significantly reduced with prolonged of waterlogging duration. KY16 and DMY1 RuBP carboxylase activities were reduced by 54.07% and 49.83% after waterlogging for 9 days and 52.92% and 51.06% after subsurface waterlogging for 15 days at the seedling stage in contrast to control.

Waterlogging results depends on the genotype, environmental factors, stage of growth and the period of waterlogging. Excessive waterlogging effect is lack of oxygen which reduced root respiration, photosynthesis and CO_2 assimilation (Li *et al.,* 2011; Prasanna and Rao, 2014). SPAD value, associated photosynthetic enzymes and photochemical proficiency of PSII reducing with expansion waterlogging time, resulting in a crucial reduction in output (Ren *et al.,* 2014; Mano and Omori, 2015).

Kumutha *et al.* (2009) recorded that the waterlogging stress on pigeon peas reduces the area of the leaves and accelerates the leaf senescence of the leaves by reducing the total content of Chl in leaves, thereby restricting the successful photosynthesis cycle and resulting in a major reduction in crop production. Under waterlogging, the phytology and catabolism of plants are disrupted. Restricted stomatal conductance, the transition of gases, metabolism of CO_2, and root hydraulic conductivity are some of the key results in waterlogged plants. Reduction of CO_2 entering the leaf which reduced transpiration leading to wilting of the leaves and decreased Chl content as a result lower dry matter accumulation (Ashraf, 2012).

2.1.3 Effect on plant anatomy

When plants are exposed to waterlogging, chloroplasts are easily damaged (Ren *et al.* 2016) and aerenchyma formation in shoots is a feasible anatomical method for screening waterlogging tolerance in maize and barley (Yamauchi *et al.,* 2014; Zhang *et al.,* 2016). Abd El-Aal and Rania, (2018) showed that the thickness of the upper epidermis, lower epidermis, palisade tissue, spongy tissue, blade thickness, upper collenchyma layers thickness, lower collenchyma layers thickness, phloem thickness, xylem tissue thickness, the number of xylem rows, thickness of widest xylem vessel, the length of midrib vascular bundle, the width of midrib vascular bundle and the thickness of leaf midrib were increased with the application of a different dose of lithovit (250 and 500 mg L^{-1}) and amino acids (2 and 4 ml L^{-1}) compared to untreated plants.

One of the main core stresses of waterlogged or flooded is oxygen deficiency in the root zone. Jiang and Wang, (2006) to investigate the anatomical change and showed that the development of aerenchyma was increased at waterlogged 15 cm and 5 cm. Within waterlogging, mitochondrial swelling occurred, especially at waterlogged 1 cm. Partial waterlogging at 15 cm and 5 cm may have a crucial impact on the development of turf grass and physiological activities. Plant lenticels are thought to be engaged in the downward transfer of oxygen and various anaerobic metabolism out growth (ethanol, CO_2 and CH_4) within the plants. But, the concrete physiological function of lenticels is ambiguous; their existence is related to plants in waterlogging tolerance (Parelle *et al.,* 2006). Plants under flooding/waterlogging conditions show many anatomical changes. Under waterlogging period, plants form adventitious root, lenticels hypertrophy and/or aerenchyma (Ashraf, 2012) adjustment to adverse conditions.

2.1.4 Effect on nutrient availability

Waterlogging increases phosphate concentrations due to bacterial transformations (Lamers *et al.,* 2006). Changes in phosphate levels and often lower nitrate levels occur simultaneously due to their denitrification loss or ammonium reduction. NO^{3-} nitrification production is inhibited because there is insufficient oxygen availability. Potassium and iron availability is also affected by waterlogging. When iron concentrations may increase, potassium concentration decreases due to an exchange of soil particles (Antheunisse and Verhoeven, 2008). Waterlogging create adverse effects on numerous biochemical and morpho-physiological system of crops by inducing insufficiency of essential nutrients (Ashraf, 2012). Akhtar and Nazir, (2013) also reported flooding negatively affected plant growth and macro and micronutrients uptake. Stress can reduce nutrient intake under stress the growth of various plant parts including the roots and the aerial part is adversely affected as a result of less plant nutrient intake and ultimately reduces plant growth (Miransari, 2014; Li *et al.,* 2015).

2.1.5 Effects on yield

Tolerant and sensitive type of mungbean genotypes including T44 and MH–96–1 (tolerant) and Pusa Baisakhi and MH–1K–24 (sensitive) were experimented by Kumar *et al*. (2013) to show the yield loss were 20.01%, 33.79% and 51.88%, respectively for 3, 6 and 9 days waterlogging. Tolerant cultivar could recover yield loss but sensitive cultivars 20% yield loss recorded at 3 days waterlogging. Lower yield loss in tolerant cultivars under 9 days waterlogged where sensitive cultivars showed 70% to 84.9% yield loss.

Waterlogging is the responsible for significant yield reduction in world wide. It has been recorded about 25% of soybean yield loss and waterlogging at reproductive stage is mainly responsible for yield reduction in soybean. At the vegetative stage 17% to 43% and reproductive stage 50% to 56% yield decline was observed (Mustafa and Komatsu, 2014).

Waterlogging induced several physiological disturbances, including reduction in growth, dry matter, photosynthesis and pod formation that resulted in low yield similar to that in other beans (Solaiman *et al.,* 2007; Pociecha *et al.,* 2008; Celik and Turhan, 2011). Waterlogging treatment caused reduction in plant growth in terms of leaf area and growth rate in all the genotypes and the level of reduction was more pronounced in sensitive genotypes.

Waterlogging reduced seed yield primarily by reducing the number of pods per plant and pod setting. Similar reductions in plant yield have been reported in snap bean mung bean (Ahmad *et al.,* 2003; Ahmed *et al.,* 2002) grown under waterlogging. Genotypic sensitivity to waterlogging could be related to the level of endogenous plant hormones, which increase dropping of flowers and/or the loss of pod setting, as also observed in other crops (Umaharan *et al.*, 1997) and induced by ethylene (Zhou and Lin 1995).

Palta *et al.* (2010) the higher number pods in tolerant cultivars was probably due to greater availability of the source to the reproductive sinks. Higher yield in tolerant cultivars resulted with increases in the number of pods, higher rate of photosynthesis and availability of plant nitrogen under waterlogging. On the other hand large reduction in root nodule number and dry matter in the sensitive genotypes indicated that subsurface waterlogging might have reduced nitrogen fixation (Matsunami *et al.*, 2005).

2.2 Role of IAA

2.2.1 Plant height

Muthulakshmi and Pandiyarajan (2015) conducted an experiment to study the IAA foliar spray on vegetative growth, physiological and biochemical constituents of *Chataranthus roseus* (L). G. Don. 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, NRA and peroxidase activity were recorded after IAA treatment.

Abel and Theologis (2010) conducted an experiment and found that auxin is involved in mitotic activity in sub-apical tissues, resulting in increased plant growth. In a pot experiment Rastogi *et al.* (2013) found that auxin and gibberellic acid enhanced vegetative growth of linseed. They concluded that 0.5 mg L^{-1} dose of auxin is recommended for the enhancement of vegetative growth. However, it was observed that IAA had more promotory effects than GA in the enhancement of vegetative growth. Among PGRs, auxin and gibberellin play vital role in regulating developmental processes within plant bodies (Gou *et al.*, 2010). A higher concentration of gibberellins increases plant growth (Bora and Sarma 2006) while higher concentration of auxin inhibits it (Hussain *et al.*, 2010a).

Quaderi *et al.* (2006) found that plant height increased effectively by IAA application in mungbean and onion respectively. Saha *et al.* (1996) reported that IAA concentration of 600 and 900 ppm applied at the beginning of the tillering stage in Kanchan variety of wheat increased plant height compared to control and 300 ppm IAA.

2.1.2 Number of leaves plant^{-1}

Gurdev and Saxena (1991) conducted and experiment on wheat and reported that IAA applied at 10-4M increased number of leaves plant^{-1}. Mathur (1971) also mentioned about similar increase in leaf number in onion treated with IAA at 100-300 ppm.

Khalil and Mandurah (1989) conducted 2-year pot trails on cowpea and found that at 15, 25, 45 of 65% of water holding capacity of soil and sprayed with 0, 10, 50 or 100 ppm IAA at 4, 6 and 9 weeks after sowing, IAA increased the number of leaves only when applied at 10 of 50 ppm at 25-65% water holding capacity.

2.1.3. Number of branches plant^{-1}

Naeem *et al.* (2004) concluded that in control plants the number of branches recorded were 2 after 30 days. However, GA_3 revealed no branching after 30 days i.e., a single main branch was only present. In 500 mg L^{-1} IAA the number of branches increased up to 4 after 30 days. Kinetin showed no increase or decrease in the number of branches as compared to control. In mixed dose of GA_3 + IAA GA_3 + kinetin branching was delayed and only one branch was observed. On the other hand IAA + kinetin had more number of branches i.e., 4 after 30 days as compared to control. The combined effect of GA_3 + IAA + kinetin showed insignificant increase as compared to control.

Malik *et al.* (2006) observed multiple shoot formation by applying cytokinin in Pisumsativum. Application of GA_3 showed a single main branch after 30 days. More number of branches were observed in IAA treatment as compared to control. Applied kinetin induced more branching in lentil. The mixed dose of GA_3 + IAA and GA_3 + kinetin showed decrease in the number of branches. However, IAA + kinetin exhibited more number of branches. When all the three plant growth regulators were applied, a significant decrease was observed in the number of branches as compared to control.

2.1.3 Root

Fukaki *et al.* (2007) studied on the developmental mechanisms of lateral root development and found that auxin has emerged as a central regulator of lateral root development. However, few scientists said that correct auxin localization and subsequent auxin response are crucial for lateral root development (Casimiro *et al.,* 2003; De Smet *et al.,* 2006).

Auxin is found directly involved in activating the cell cycle during lateral root initiation (Himanen *et al.*, 2004) and the expression of genes downstream (Himanen *et al.*, 2004; Vanneste *et al.,* 2005).

Casimiro *et al.* (2003) in an experiment found that auxin is the major regulator of lateral root initiation, differentiation and meristem specification. Manikandan and Hakim (1998) reported increased root length when IAA was applied at 30 ppm as foliar spray in groundnut.

2.1.4 Flower and pod dropping

Mondal *et al.* (2011) reported that seed yield is strongly correlated with the number of opened flowers and number of produced mature pods.

Fakir *et al.* (2011) conducted an experiment on mungbean and concluded that high yielding genotypes of mungbean have higher number of flowers. However, in legume crops, many flowers are produced but only a few set pods are formed and result the low yield (Saitoh *et al.,* 2004; Mondal, 2007; Islam *et al.,* 2010a). The extent of abscission has been put at more than 50% in most cases (Izquierdo and Hosfield, 1981).

Lim *et al.* (2003) said that plant hormones like ethylene, abscisic acid and jasmonates induce senescence; and auxin, cytokinin and gibberellins play a role in suppressing flower and pod dropping. However, classical studies have correlated auxin levels with senescence and abscission.

2.1.5 Stover yield

Elshorbagi *et al.* (2008) mentioned about the role of IAA on the anatomical characteristics, stover and fiber yield and quality of Flax.

2.1.6 Biological yield

Sadak *et al.* (2013) conducted and experiment and found that IAA treatments caused significant increases in seed yield/plant (g), yield attributes (number of pods/plant, pods yield/plant (g), 100-seed weight (g) and biological yield/plant) of the two fababean cultivars.

2.1.7 Harvest index (%)

Quaderi *et al.* (2006) conducted an experiment and mentioned that seed treatment with 200 ppm IAA resulted the highest relative growth rate (RGR), crop growth rate (CGR), net assimilation rate (NAR), higher yield, harvest index (38.48) of mungbean.

Newaj *et al.* (2002) carried out an experiment with 300, 600 and 900 ppm IAA on mungbean and found that mungbean treated with IAA at 600 ppm performed better in case of highest pod length, number of seeds, seed yield plant^{-1} and seed yield (t ha^{-1}) than that of other treatments.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted during the period from April 2022 to July 2022 to find out the effect of IAA on mugnbean under water logging condition at pod maturity stage. The chapter includes a brief description of the location of experiment, materials used for the experiment, transplanting, intercultural operation, data collection, data recording and their analysis procedure which are presented below under the following headings-

3.1. Experimental site

The experiment was conducted at Sher-e-Bangla Agricultural University, Dhaka. The location of the study site was situated in 23°74′N latitude and 90°35′E longitudes. The altitude of the location was 8m from the sea level as per the Bangladesh Metroeological Department, Agargaon, Dhaka-1207, which have been shown in the Appendix I.

3.2 Agro-ecological region

The experimental site belongs to the agro-ecological zone of "Madhupur Tract", AEZ-28 (Anon., 1988a). This was a region of complex relief and soils developed over the Madhupur clay, where floodplain sediments buried the dissected edges of the Madhupur Tract leaving small hillocks of red soils as "islands" surrounded by floodplain (Anon., 1988b).

3.3 Characteristics of soil

It was a medium high land with adequate irrigation facilities and remains fallow during previous growing season. The nutrient status of the farm soil under the experimental pot was collected and analyze in the Soil Resource Development Institute (SRDI), Dhaka and result has been presented in Appendix II & III.

3.4 Climate condition of the experimental site

The geographical location of the experimental site was under the sub-tropical climate characterized by three distinct seasons. The monsoon or rainy season extending from May to October, which is associated with high temperature, high humidity and heavy rainfall; the winter or dry season from November to February, which is associated with moderately low temperature and the premonsoon period or hot season from March to April, which is associated with some rainfall and occasional gusty winds. The weather information regarding temperature, rainfall, relative humidity and sunshine hours prevailed at the experimental site during the cropping season April 2022 to July 2022 have been presented in Appendix IV.

3.5 Planting materials

BARI Mung-6 was used as planting material. The seeds of BARI Mung-6 were collected from Bangladesh Agricultural Research Inistitute, Joydepur, Gazipur. This variety is suitable for summer season. The plant height of the variety ranges from 60-70 cm. It is resistant to *Cercospora* leaf spot and yellow mosaic diseases. It's life cycle ranges from 60-65 days after sowing (DAS) and average yield is 1400-1600 kg ha^{-1}.

3.6 Treatments of the experiment

The experiment comprised of two factors

Factor A: Water logging (2 levels)

W_0 = No water logging
W_e = Water logging at pod maturity stage

Factor B: Different level of IAA (5 levels)

I_0 = Only spray water (Control)
I_{50} = Spray of IAA @ 50 ppm at 15 DAS and 2 days after stress imposition
I_{100} = Spray of IAA @ 100 ppm at 15 DAS and 2 days after stress imposition
I_{150} = Spray of IAA @ 150 ppm at 15 DAS and 2 days after stress imposition
I_{200} = Spray of IAA @ 200 ppm at 15 DAS and 2 days after stress imposition

Table 1. Arrangement of different level of waterlogging (Factor A) and different level of IAA (Factor B)

Factor A		Factor B		Combinations of Factor A and Factor B
Level	**Description**	**Level**	**Description**	
W_0	No water logging	I_0	No IAA	W_0I_0
		I_{50}	Spray of IAA @ 50 ppm	W_0I_{50}
		I_{100}	Spray of IAA @ 100 ppm	W_0I_{100}
		I_{150}	Spray of IAA @ 150 ppm	W_0I_{150}
		I_{200}	Spray of IAA @ 200 ppm	W_0I_{200}
W_e	Water logging at pod maturity stage	I_0	No IAA	W_eI_0
		I_{50}	Spray of IAA @ 50 ppm	W_eI_{50}
		I_{100}	Spray of IAA @ 100 ppm	W_eI_{100}
		I_{150}	Spray of IAA @ 150 ppm	W_eI_{150}
		I_{200}	Spray of IAA @ 200 ppm	W_eI_{200}

3.7 Experimental design

The two factors experiment was laid out in a Completely Randomized Design (CRD) with four replications. Thus 40 experimental pots were placed in ambient air at the research Farm premises of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh.

3.8 Preparation of soil and filling of pots

There were 40 earthen pots. The size of the pot was 30 cm top diameter with a height of 25 cm. Top soil was collected from experimental field and then pulverized. The inner materials, visible insects, pests and plants properties were sorted. Then the soil was dried thoroughly. Compost (¼ of the soil volume) and 0.2g Urea 0.4g TSP and 0.12g MoP per pot were incorporated uniformly into the soil, which was correspond to the rate of @ 45, 100, 60 and 1 kg ha^{-1} of Urea, TSP, MoP, BA and 10 t ha^{-1} cowdung, respectively. Each pot was then filled with 8 kg previously prepared growth media (soil and cowdung mixture). Treatments were replicated four times. Eight seeds had chosen and sowed in each pot at a depth of 1cm. Intercultural operation, weeding and other measures were taken when necessary.

3.9 Sowing of seeds in the pot

The seeds of mungbean were sown on April 05, 2022. Before sowing seeds were treated with Bavistin to control the seed borne diseases. The seeds were sown in the soil of pots maintaining a depth of 2-3 cm.

3.10 Intercultural operation

3.10.1 Thinning

Seeds started to germinate after three days after sowing (DAS). Thinning was done two times: first thinning was done at 5 DAS and second was done at 15 DAS to maintain optimum plant population (9 plants/pot at early stage and 5 plants at later stage) in each Pot.

3.10.2 Weeding

The pots were weeded when emerged any weed by hand picking.

3.10.3 Protection against insect and pest

At early stage of growth few worms (*Agrotis ipsilon*) and virus vectors (jassid) infested the young plants and at later stage of growth pod borer (*Maruca testulais*) attacked the plant. Dimacron 50EC was sprayed at the rate of I litre/ha to control the pest.

3.11. Harvesting of crop

Harvesting was done when 90% of the pods became brown to black in color. The matured pods were collected by hand picking from each pot. Harvesting was done after 75 days after sowing.

3.12 Collection of data

The following parameters were considered for data collection.

Phenological parameters

a. Days of maturity

Crop growth parameters

a. Plant height (cm)

b. Branch no. plant^{-1}

c. Above ground fresh weight plant^{-1} (g)

d. Above ground dry weight plant^{-1} (g)

e. Pod length (cm)

Physiological parameters

a. SPAD value of leaf

b. Relative water content (RWC)

Yield and yield contributing parameters

a. Thousand seed weight (g)

b. Number of pods plant^{-1}

c. Seed yield per plant (g)

3.13 Procedure of data collection

As there were five plants in each pot, so all plant were selected for collection of data.

3.13.1 Plant height (cm)

Plant height was measured from sample plants in centimeter from the ground level to the tip of the longest stem of five plants and mean value was calculated. Plant height was measured with a meter scale from five plants at 15, 30, 45 and 60 DAS.

3.13.2 Number of branches plant^{-1}

The number of branches plant^{1} was counted from five plant of each pots at 15, 30, 45 and 60 DAS. The average number of branches per plant was determined and recorded.

3.13.3 Days to 1st flowering

Days to 1st flowering was recorded by counting the number of days required to start flower initiation in each pot.

3.13.4 Days to 1st maturity of pod

Days to 1st maturity of pod was recorded by counting the number of days required to attain 1st maturity of pods. Maturity was measured on the basis of brown colour of leaves and stem and dark grey colour of pods.

3.13.5 Pod length

The length of pod was measured with a meter scale from the neck to the bottom of pod from each pot and their average was taken and expressed in cm.

3.13.6 No. of pods per plant

Number of pods per plant was counted by unit pot wise from five selected plants and then averaged after harvesting.

3.13.7 Above ground fresh weight plant^{-1}

After harvest, above ground fresh weight of all plants in each pot were collected. At harvest, fresh weight of five plants per plot was weighed by balance and their mean value was calculated as plant fresh weight was expressed in gram (g).

3.13.8 Above ground dry weight plant^{-1}

After harvest, plants were kept for drying as a natural condition and after sun drying; Sundry weight of plants was measured from each treatment and then weighted which expressed as gram (g). Five plants of each plot were cut down and oven dried at temperature of 60°C for 72 hours and was weighed in gram by an electrical balance.

3.13.9 SPAD value of leaf

Chlorophyll content of leaf was measured by SPAD meter (SPAD 502 chlorophyll meter). Data was recorded from 9 leaves of each sampling plant and it was done during the pod filling stage.

3.13.10 Relative water content (RWC)

Leaf relative water content (RWC) was determined by recording the turgid weight of 0.5 g fresh leaf samples by keeping in water for 4 h, followed by drying in hot air oven till constant weight achieved (Weatherley 1950).

$$\text{RWC (\%)} = \frac{\text{Fresh weight} - \text{dry weight}}{\text{Turgid weight} - \text{dry weight}} \times 100$$

3.13.11 Thousand seed weight (g)

Weight of thousand seeds were measured by an electric balance after sun drying. Thousand seeds weight of each unit pot measured separately during the harvesting period and was expressed in gram (g).

3.13.12 Seed yield per plant (g)

An electric balance was used to measure the weight of Mungbean seeds per plot. The total yield of each pot measured separately during the harvesting period and was expressed in gram (g)

3.14 Statistical analysis

The data obtained for different parameters were statistically analyzed to find out the significant difference of different IAA levels and different levels of water logging on the reproductive behavior and yield attributes of mungbean. The mean values of all the characters were calculated and analysis of variance was performed by the 'F (variance ratio) test. The significance of the difference among the treatment means was estimated by the Least Significant Difference (LSD) at 5% level of probability (Gomez and Gornez, 1984).

CHAPTER IV

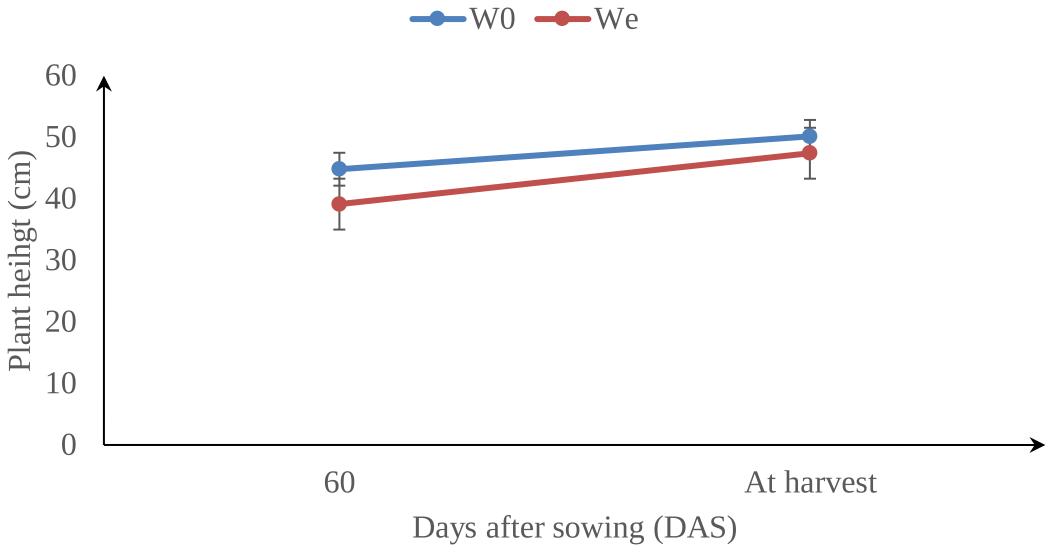
RESULTS

This chapter contains the presentation and discussion of the results obtained from the present study. Results have been presented, discussed and possible interpretations were made through tables and graphs. The results obtained from this experiment have been presented under separate headings and sub-headings as follows:

4.1 Plant height

4.1.1 Effect of water logging

Waterlogging greatly affects growth parameters. Waterlogged mungbean plants showed remarkably decreased plant height compared to control plants. Significant difference was recorded for different water logging conditions on plant height at 60 DAS and harvest (Fig. 1). At 60 DAS. the tallest plant (44.80 cm) was observed from W_0 (control i.e. no water logging) and the shortest plant (39.13 cm) was observed from W_e (Water logging at pod maturity stage). Similarly, at harvest, the tallest plant (50.14 cm) was observed from W_0 (control i.e. no water logging) and the shortest plant (47.4 cm) was observed from W_e (Water logging at pod maturity stage). The results of the experiment are in agreement with Ullah (2006), who found that plant height continued increasing up to maturity. Control plants showed the highest plant height at all the growth stages. It decreased significantly as the length of water logging was increased. At maturity, control showed highest plant height (60 cm).

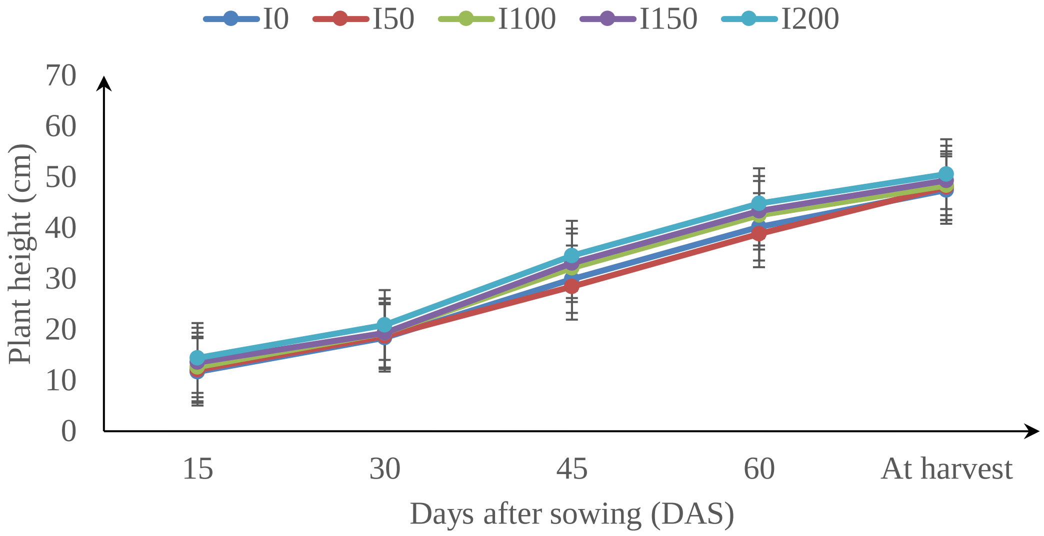


[Here, W_0 = No water logging; W_e = Water logging at pod maturity stage]

Figure 1. Effect of water logging at pod maturity stage on plant height of mungbean at different days after sowing (DAS) [$LSD_{(0.05)}$ = 0.20, 0.21, 1.22, 1.22 and 1.80 at 15, 30, 45, 60 DAS and at harvest, respectively]

4.1.2 Effect of IAA

Application of IAA with different concentrations showed significant influence on plant height of BARI Mung 6 (Fig. 2). Plant height was increased with increasing IAA concentration. The tallest plant of BARI Mung 6 was found in I_{200} (200 ppm IAA application) treatment at 15, 30, 45, 60 DAS and harvest (14.42 cm, 20.91 cm, 34.54 cm, 44.88 cm and 50.60 cm respectively). On the other hand, control treatment I_0 (No IAA application) showed the lowest plant height of BARI Mung 6 at different growth stage (11.69 cm at 15 DAS, 18.37 cm at 30 DAS, 29.92 cm at 45 DAS, 40.23 cm at 60 DAS and 47.47 cm at harvest). Auxin appears to be a pattern-determining global regulator, as well as a player in cell division, cell elongation and vascular tissue differentiation. So, foliar application of IAA may enhance the physiological process of plant which could be the reason for higher plant height of IAA treated plants in this experiment. Abel and Theologis (2010) reported that exogenous application of auxin increased the plant growth. Rastogi *et al.* (2013), Sontakey *et al*. (1991) and Rahman *et al.* (1989) mentioned higher plant height after IAA application.



[Here, I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition]

Figure 2. Effect of IAA on plant height of mungbean at different days after sowing (DAS) [$LSD_{(0.05)}$ = 0.31, 0.33, 1.93, 1.93 and 0.28 at 15, 30, 45, 60 DAS and at harvest, respectively]

4.1.3 Interaction effect of waterlogging and IAA

In this experiment significant interaction effect of water logging and IAA was observed on plant height (cm) for BARI Mung 6 at different days after sowing (DAS) (Table 2). The highest plant height was recorded in W_0I_{200} (no water logging condition with application of 200 ppm IAA) treatment combination at 15, 30, 45, 60 DAS and at harvest (15.08 cm, 22.04 cm, 36.45 cm, 46.79 cm and 52.36 cm, respectively) (Table 2). On the other hand, the lowest plant height was recorded in W_eI_0 (water logging condition with no application of IAA) treatment combination at all the growth stage of plant (10.14 cm at 15 DAS, 17.29 cm at 30 DAS, 27.59 cm at 45 DAS, 37.93 cm at 60 DAS and 46.62 cm at harvest).

Table 2. Interaction effect of water logging at pod maturity stage and IAA on plant height plant^{-1} of mungbean at different days after sowing (DAS)

Treatments	Plant height plant^{-1} (cm)	
	60 DAS	At harvest
W_0I_0	42.54 c-e	48.53 e
W_0I_{50}	43.93 bc	49.20 d
W_0I_{100}	45.11 a-c	49.63 c
W_0I_{150}	45.63 ab	50.97 b
W_0I_{200}	46.79 a	52.36 a
W_eI_0	37.93 f	46.62 h
W_eI_{50}	33.70 g	46.91 g
W_eI_{100}	39.91 ef	47.07 g
W_eI_{150}	41.15 de	47.75 f
W_eI_{200}	42.97 b-d	48.84 de
$LSD_{(0.05)}$	2.72	1.39
CV (%)	4.49	1.57

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

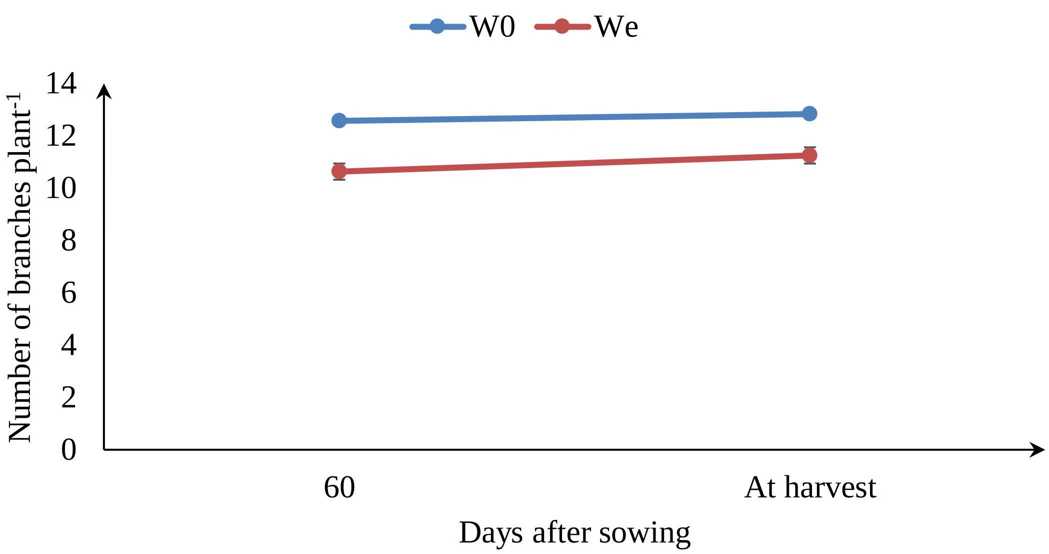
[Here, W_0 = No water logging; W_e = Water logging at pod maturity stage; I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition]

4.2 Branch number per plant

4.2.1 Effect of water logging

Significant difference was recorded for different water logging conditions on number of branches per plant at 60 DAS and harvest (Fig. 3). At 60 DAS. the highest number of branches plant^{-1} (12.57) was observed from W_0 (control i.e. no water logging) and the lowest number of branches plant^{-1} (10.63) was observed from W_e (Water logging at pod maturity stage). Similarly, at harvest, the highest number of branches plant^{-1} (12.83) was observed from W_0 (control i.e. no water logging) and the lowest number of branches plant^{-1} (11.25) was observed from W_e (Water logging at pod maturity stage).

Cho and Yamakawa (2006a) showed the number of leaves, branch number, nodulation significantly reduced due to waterlogging in soybean. Miura *et al.* (2012) also reported that waterlogging treatment at 21 days in soybean, reduced the number of branches significantly. At the vegetative stage, prolonged waterlogging greatly reduced branch number in mungbean (Koyama *et al.*, 2019; Ahmad *et al.*, 2003) and decreased 50% branch number in chickpea (Paltaa *et al.*, 2010).

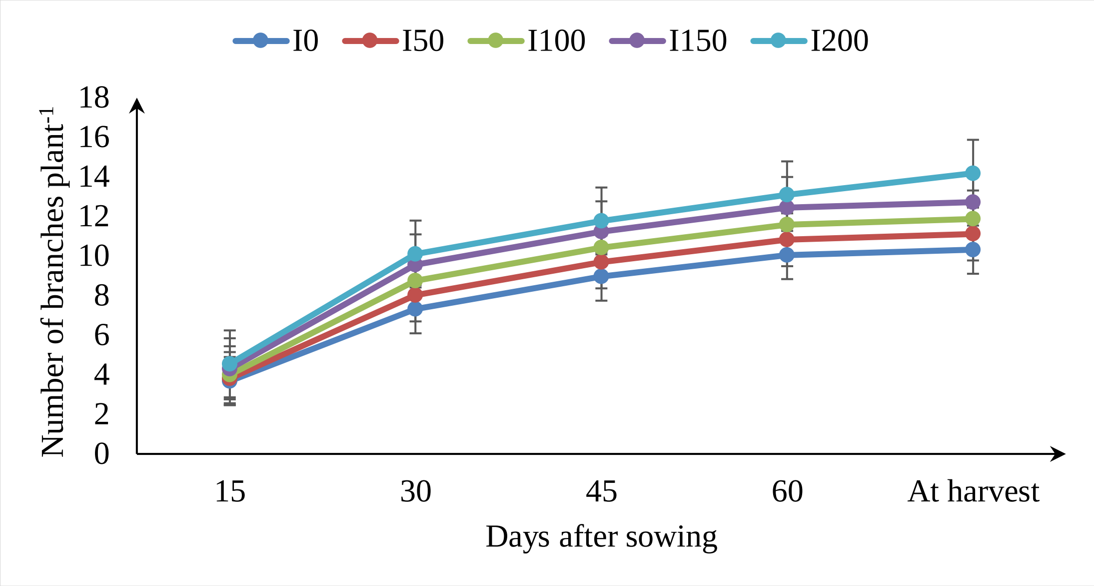


[Here, W_0 = No water logging; W_e = Water logging at pod maturity stage]

Figure 3. Effect of water logging at pod maturity stage on number of branches plant^{-1} of mungbean at different days after sowing (DAS) [$LSD_{(0.05)}$ = 0.43, 0.57, 0.57, 0.57 and 4.98 at 15, 30, 45, 60 DAS and at harvest, respectively]

4.2.2 Effect of IAA

Application of IAA with different concentrations showed significant influence on number of branches plant^{-1} of BARI Mung 6 at different days after sowing (Fig. 4). Number of branches per plant^{-1} was increased with increasing IAA concentration. The highest number of branches per plant was found in I_{200} (200 ppm IAA application) treatment at 15, 30, 45, 60 DAS and at harvest (4.55, 10.1, 11.77, 13.09 and 14.18 respectively). On the other hand, control treatment I_0 (No IAA application) showed the lowest number of branches plant^{-1} of BARI Mung 6 at different growth stage (3.68 at 15 DAS, 7.31 at 30 DAS, 8.96 at 45 DAS, 10.05 at 60 DAS and 10.32 at harvest).



[Here, I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition]

Figure 4. Effect of IAA on number of branches plant^{-1} of mungbean at different days after sowing (DAS) [$LSD_{(0.05)}$ = 0.67, 0.90, 0.90, 0.90 and 7.87 at 15, 30, 45, 60 DAS and at harvest, respectively]

4.1.3 Interaction effect of waterlogging and IAA

In this experiment significant interaction effect of water logging and IAA was observed on number of branches plant^{-1} for BARI Mung 6 at different days after sowing (DAS) (Table 3). The highest number of branches plant^{-1} was recorded in W_0I_{200} (no water logging condition with application of 200 ppm IAA) treatment combination at 15, 30, 45, 60 DAS and at harvest (4.90, 10.41, 12.08, 13.53 and 13.80, respectively) (Table 3). On the other hand, the lowest number of branches plant^{-1} was recorded in W_eI_0 (water logging condition with no application of IAA) treatment combination at all the growth stage of plant (3.37 at 15 DAS, 6.77 at 30 DAS, 8.44 at 45 DAS, 9.33 at 60 DAS and 9.65 at harvest).

Table 3. Interaction effect of water logging at pod maturity stage and IAA on number of branches plant^{-1} of mungbean at different days after sowing (DAS)

Treatments	Number of branches plant^{-1} (no.)	
	60 DAS	At harvest
W_0I_0	10.76 d-f	10.99 b
W_0I_{50}	11.72 c-e	11.98 ab
W_0I_{100}	12.73 bc	12.99 ab
W_0I_{150}	13.53 ab	13.80 ab
W_0I_{200}	14.12 a	14.40 ab
W_eI_0	9.33 g	9.65 b
W_eI_{50}	9.92 fg	10.24 b
W_eI_{100}	10.44 e-g	10.75 b
W_eI_{150}	11.36 c-e	11.65 ab
W_eI_{200}	12.07 cd	23.97 a
$LSD_{(0.05)}$	1.27	11.12
CV (%)	7.60	9.07

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

[Here, W_0 = No water logging; W_e = Water logging at pod maturity stage; I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition]

4.3 Days to maturity

4.3.1 Effect of waterlogging

Statistically significant variation was observed in case of different water logging treatments for days to maturity of mungbean (Table 4). The minimum days (56.95) to maturity was observed from W_0 (control i.e. no water logging) whereas the maximum days (62.20) was recorded from W_e (Water logging at pod maturity stage). The results of the experiment are in agreement with Ullah (2006), who found that flowering and maturity were found to be significantly delayed as the days of water logging was increased. However, duration of pod development (Days from 50 % flowering to 80 % maturity) was hastened due to increased period of water logging.

4.3.2 Effect of IAA

Significant variation was found for different levels of IAA on days to maturity of mungbean (Table 4). The maximum days (62.00) to maturity was found from I_0 (No IAA application) which was statistically different from all other treatments and followed by I_{50} (60.75 days) whereas the minimum days (56.63) to maturity was recorded from I_{200} (200 ppm IAA application) followed by I_{150} (56.63 days). From the finding it was revealed that the days of maturity was decreased with increase of IAA concentration.

Table 4. Effect of water logging at pod maturity stage and different level of IAA on days to 1st maturity of mungbean

Factors	Days to 1st maturity
Factors-A	
W_0	56.95 b
W_e	62.20 a
LSD$_{(0.05)}$	3.34
CV (%)	1.91
Factor-B	
I_0	62.00 a
I_{50}	60.75 ab
I_{100}	60.00 bc
I_{150}	58.50 c
I_{200}	56.63 d
LSD$_{(0.05)}$	1.55
CV (%)	1.91

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

[Here, W_0 = No water logging; W_e = Water logging at pod maturity stage; I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition]

4.4.3 Interaction effect of waterlogging and IAA

In this experiment significant interaction effect of water logging and IAA was observed on days to maturity for BARI Mung 6 (Table 5). The minimum days (53.75) to maturity was recorded in W_0I_{200} (no water logging condition with application of 200 ppm IAA) treatment combination which was statistically identical from all other treatment and followed by W_0I_{150} (55.75 days). On the other hand, the maximum days (64.50) to maturity was recorded in W_eI_0 (water logging condition with no application of IAA) treatment combination followed by W_0I_{50} (63.25 days).

Table 5. Interaction effect of water logging at pod maturity stage and different level of IAA on days to 1st maturity of mungbean

Interaction	Days to 1st maturity
W_0I_0	59.50 d
W_0I_{50}	58.25 e
W_0I_{100}	57.50 e
W_0I_{150}	55.75 f
W_0I_{200}	53.75 g
W_eI_0	64.50 a
W_eI_{50}	63.25 b
W_eI_{100}	62.50 b
W_eI_{150}	61.25 c
W_eI_{200}	59.50 d
$LSD_{(0.05)}$	0.78
CV (%)	1.91

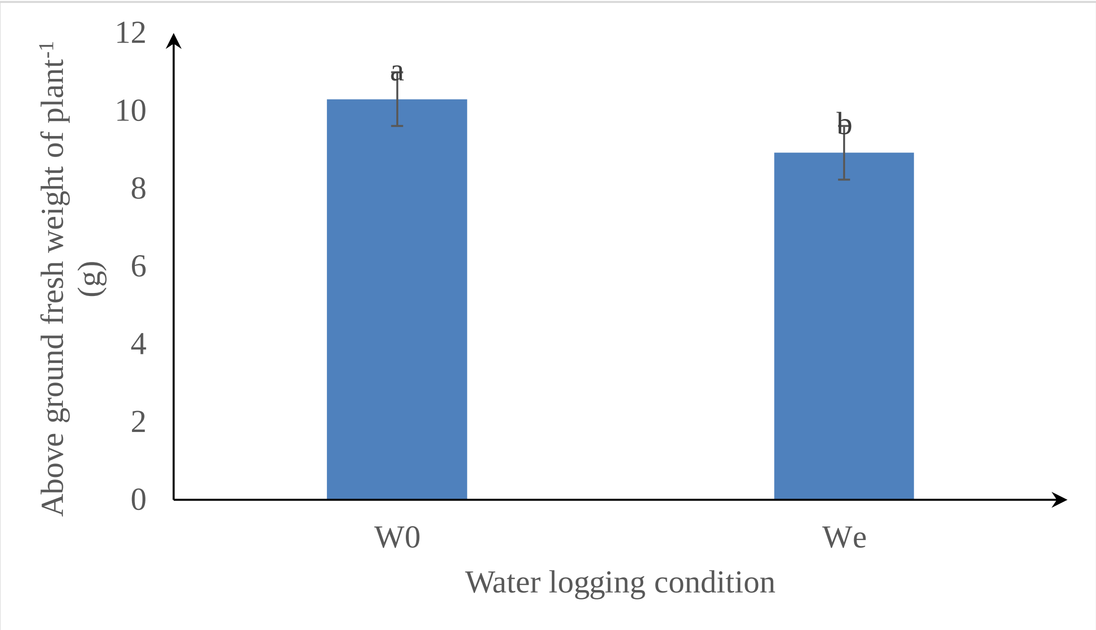
In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

[Here, W_0 = No water logging; W_e = Water logging at pod maturity stage; I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition]

4.4 Above ground fresh weight plant^{-1} (g)

4.4.1 Effect of water logging

The above ground fresh weight of plant^{-1} of BARI Mung 6 at harvest was significantly influenced by water logging condition (Fig/ 5). The maximum above ground fresh weight plant^{-1} (10.3 g) was recorded from W_0 (control i.e. no water logging) and the minimum above ground dry weight plant^{-1} (8.92 g) was recorded from W_e (Water logging at pod maturity stage).

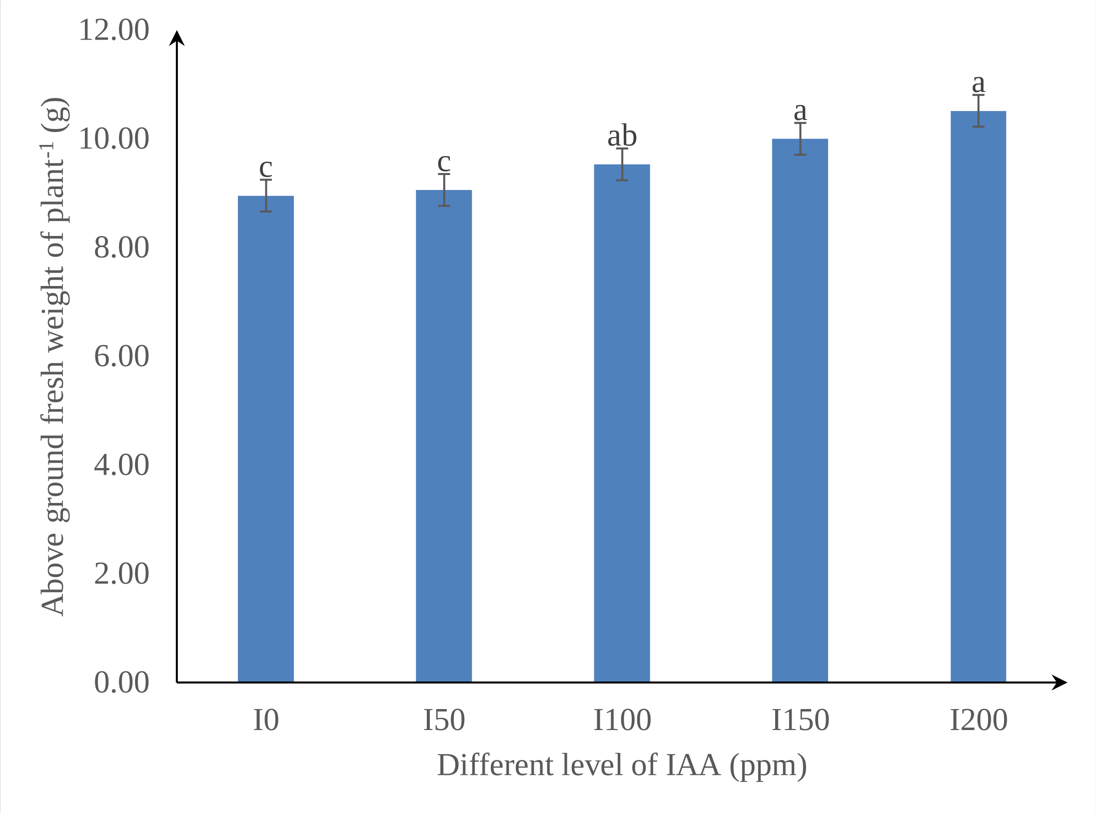


[Here, W_0 = No water logging; W_e = Water logging at pod maturity stage]

Figure 5. Effect of water logging at pod maturity stage on above ground fresh weight plant^{-1} (g) of mungbean [$LSD_{(0.05)}$ = 1.35]

4.4.2 Effect of IAA

Application of IAA had no significant role to increase above ground fresh weight plant^{-1} (g) of mungbean (Fig. 6). Numerically, the highest above ground fresh weight plant^{-1} (10.52 g) of BARI Mung 6 was found in I_{200} (200 ppm IAA application) treatment compared to other treatments. On the other hand, control treatment I_0 (No IAA application) gave the lowest above ground fresh weight plant^{-1} of BARI Mung 6 (8.96 g).



[Here, I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition]

Figure 6. Effect of IAA on above ground fresh weight plant^{-1} (g) of mungbean
[$LSD_{(0.05)}$ = 0.89]

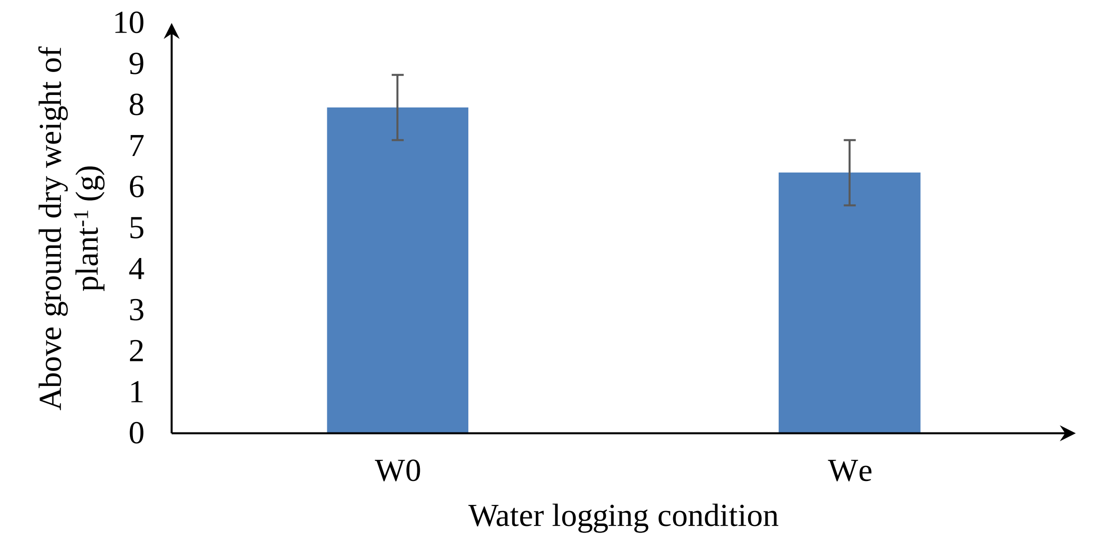
4.4.3 Interaction effect of water logging and IAA

In this experiment no significant interaction effect of water logging and IAA was observed on above ground fresh weight plant^{-1} (g) of mungbean (Table 6). Numerically, the highest above ground dry weight plant^{-1} (11.47 g) was recorded in W_0I_{200} (no water logging condition with application of 200 ppm IAA) treatment combination. On the other hand, the lowest above ground dry weight plant^{-1} (8.41 g) was recorded in W_eI_0 (water logging condition with no application of IAA) treatment combination.

4.5 Above ground dry weight plant^{-1} (g)

4.5.1 Effect of water logging

The above ground dry weight of plant^{-1} of BARI Mung 6 at harvest was not significantly influenced by water logging condition (Fig. 7). Numerically, the maximum above ground dry weight plant^{-1} (7.94 g) was recorded from W_0 (control i.e. no water logging) and the minimum above ground dry weight plant^{-1} (6.35 g) was recorded from W_e (Water logging at pod maturity stage).

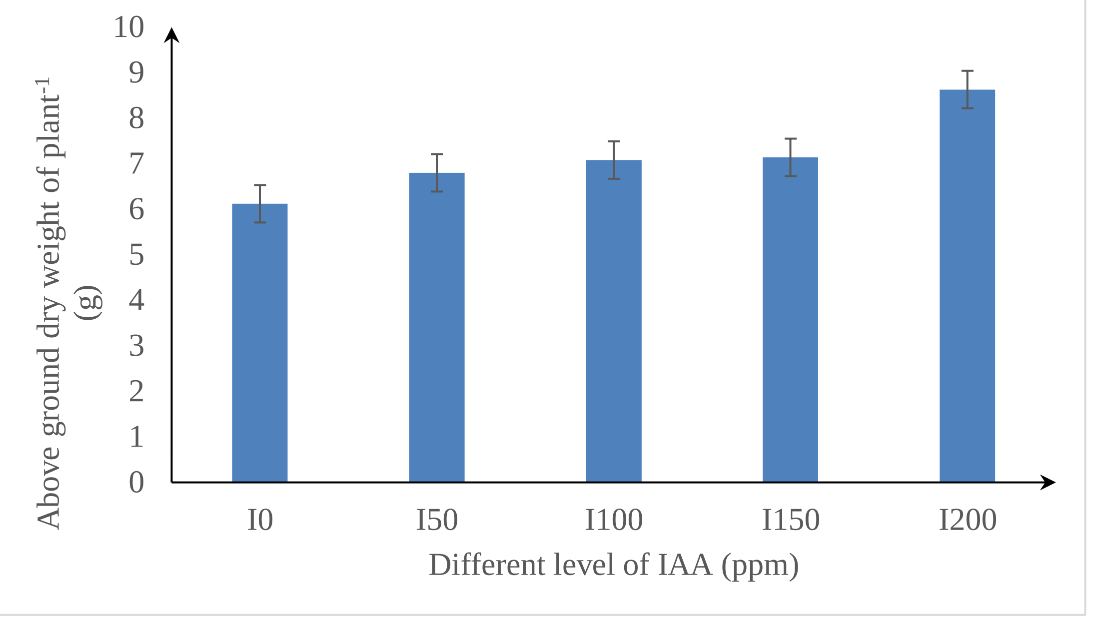


[Here, W_0 = No water logging; W_e = Water logging at pod maturity stage]

Figure 7. Effect of water logging at pod maturity stage on above ground dry weight plant^{-1} (g) of mungbean [$LSD_{(0.05)}$ = 1.69]

4.5.2 Effect of IAA

Application of IAA had no significant role to increase above ground dry weight plant^{-1} (g) of mungbean (Fig. 8). Numerically, the highest above ground dry weight plant^{-1} (8.63 g) of BARI Mung 6 was found in I_{200} (200 ppm IAA application) treatment compared to other treatments. On the other hand, control treatment I_0 (No IAA application) gave the lowest above ground dry weight plant^{-1} of BARI Mung 6 (6.12 g). Muthulakshmi and Pandiyarajan (2015) reported about increased vegetative growth characters like leaf dry weight, length of root and shoot, fresh and dry weight of shoot and root. Exogenous IAA application increased the leaf dry weight in onion at 100-300 ppm (Mathur, 1971) and in wheat treated with 10-4 M IAA (Gurdev and Saxena, 1991). Similar results were also reported by Khalil and Mandurah (1989).



[Here, I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition]

Figure 8. Effect of IAA on above ground dry weight plant^{-1} (g) of mungbean [$LSD_{(0.05)}$ = 2.67]

4.5.3 Interaction effect of water logging and IAA

In this experiment significant interaction effect of water logging and IAA was observed on above ground dry weight plant^{-1} (g) of mungbean (Table 6). The highest above ground dry weight plant^{-1} (9.76 g) was recorded in W_0I_{200} (no water logging condition with application of 200 ppm IAA) treatment combination. On the other hand, the lowest above ground dry weight plant^{-1} (5.10 g) was recorded in W_eI_0 (water logging condition with no application of IAA) treatment combination.

Table 6. Interaction effect of water logging at pod maturity stage and different level of IAA on above ground fresh weight plant^{-1} (g) and above ground dry weight plant^{-1} (g) of mungbean

Interaction	Above ground fresh weight plant^{-1} (g)	Above ground dry weight plant^{-1} (g)
W_0I_0	9.50	7.14 ab
W_0I_{50}	9.54	7.89 ab
W_0I_{100}	10.45	7.22 ab
W_0I_{150}	10.54	7.71 ab
W_0I_{200}	11.47	9.76 a
W_eI_0	8.41	5.10 b
W_eI_{50}	8.58	6.39 ab
W_eI_{100}	8.61	6.27 ab
W_eI_{150}	9.46	6.46 ab
W_eI_{200}	9.56	7.50 ab
$LSD_{(0.05)}$	0.22	3.77
CV (%)	29.96	36.57

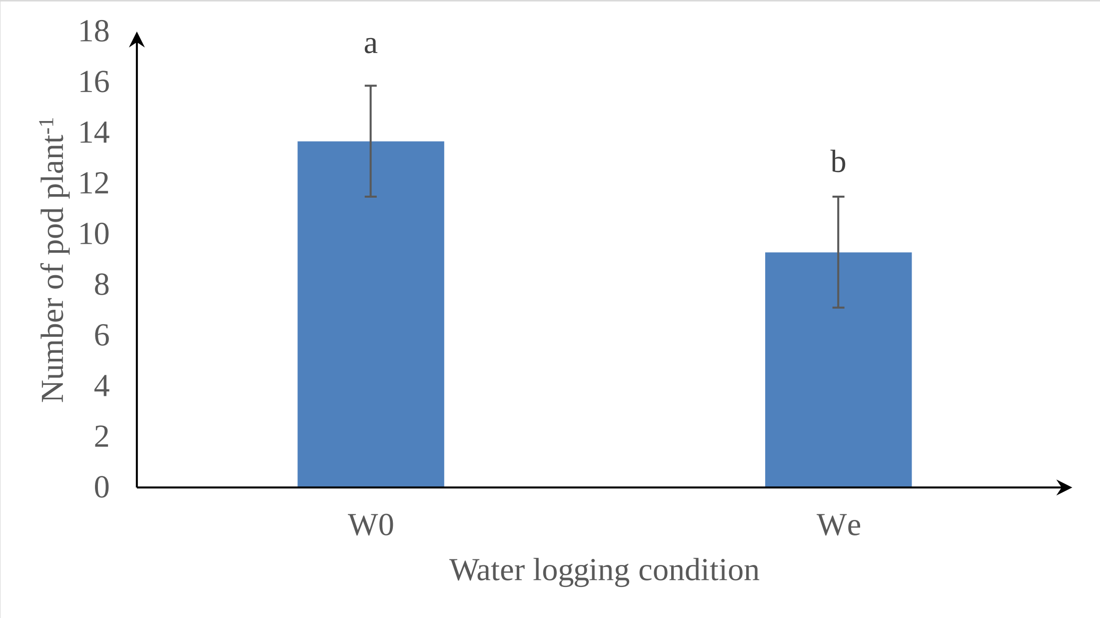
In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

[Here, W_0 = No water logging; W_e = Water logging at pod maturity stage; I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition]

4.6 Pod number plant^{-1}

4.6.1 Effect of water logging

Statistically significant variation was observed in case of different water logging treatments for number of pods of mungbean (Fig. 9). The maximum number of pods per plant (13.67) was recorded from W_0 (control i.e. no water logging) whereas the minimum number of pods of mungbean (9.29) was recorded from W_e (Water logging at pod maturity stage). The results of the experiment are in agreement with Ullah (2006), who found that number of pods was found to decrease significantly and successively with the successive increase in water logging. Similar result was also obtained by Gaffer (2020), Saha (2020) and Nusrat (2010).

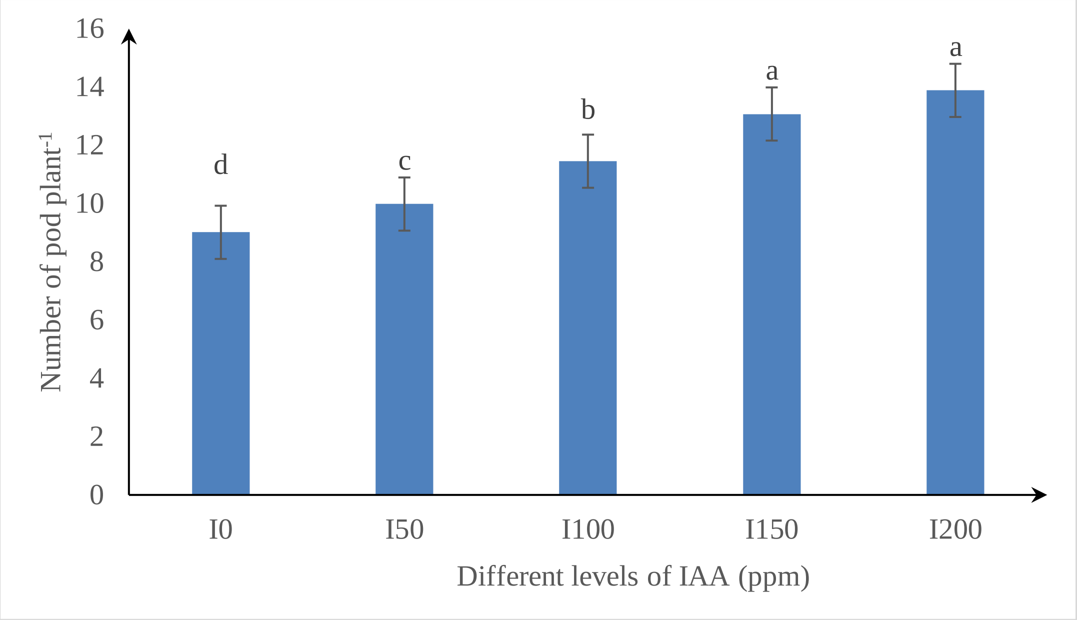


[Here, W_0 = No water logging; W_e = Water logging at pod maturity stage]

Figure 9. Effect of water logging at pod maturity stage on number of pod plant^{-1} of mungbean [$LSD_{(0.05)}$ = 0.56]

4.6.2 Effect of IAA

In this experiment, effect of IAA on number of pods plant^{-1} of BARI Mung 6 was found significant (Fig. 10). Pods plant^{-1} was increased due to the IAA application. Highest pods plant^{-1} (13.88) was recorded at I_{200} (200 ppm IAA application) (Fig. 7a). However, statistically similar result was observed in I_{150} (150 ppm IAA application) (13.07). On the other hand, lowest pods plant^{-1} (9.01) was recorded in control treatment I_0 (No IAA application). Arora *et al.* (1998) reported the regulatory effect of IAA on number of pods per chickpea plant. Application of 10-5M IAA significantly increased the number of capsules per flax plant (Abdel *et al.*, 1996) and application of 50 ppm IAA on grass pea increased number of pods per plant (Rahman *et al.*, 1989). Similar results were found by Lee (1990), Chellappa and Karivaratharaju (1973) and Manikandan and Hakin (1998) for groundnut.



[Here, I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition]

Figure 10. Effect of IAA on number of pod plant^{-1} (g) of mungbean [$LSD_{(0.05)}$ = 0.88]

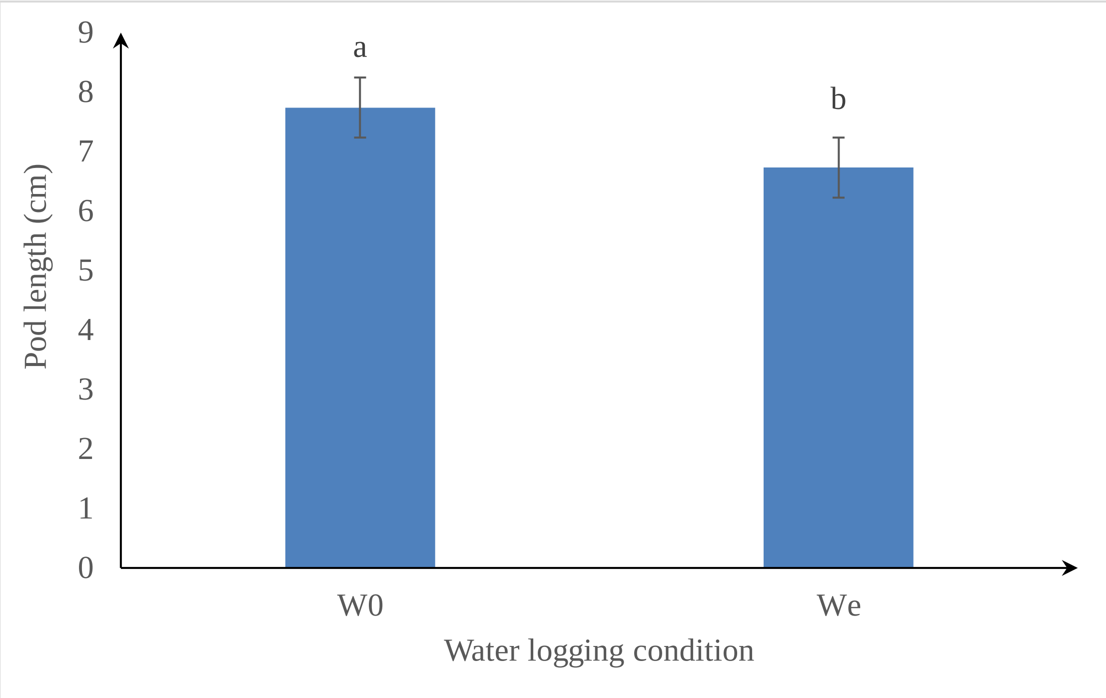
4.6.3 Interaction effect of water logging and IAA

In this experiment significant interaction effect of water logging and IAA was observed on number of pod plant^{-1} for BARI Mung 6 (Table 7). The maximum pod number plant^{-1} (17.77) to maturity was recorded in W_0I_{200} (no water logging condition with application of 200 ppm IAA) treatment combination which was statistically identical from all other treatment and followed by W_0I_{150} (16.31). On the other hand, the minimum number of pod plant^{-1} (8.17) was recorded in W_eI_0 (water logging condition with no application of IAA) treatment combination which was statistically similar with W_eI_{50} (water logging condition with application of 50 ppm IAA) (8.90) and followed by W_0I_{100} (9.52).

4.7 Pod length (cm)

4.7.1 Effect of water logging

Pod length was significantly affected by waterlogging treatment and that was measured in control and waterlogging treatment and higher pod length was observed in control condition and it was 7.74 cm (Fig. 11). Lower pod length was measured in waterlogging treatment 6.73 cm. The differences in pod length might be due to the differential genetic configuration of the genotypes. Hamid *et al.* (1991) found a similar result in Mungbean plants due to water stress. Water stress at flowering reduced pod formation, increased pod shedding and decreased grain yield in field bean (Grazesiak *et al.*, 1989). Jannat (2020) found similar type of result in mungbean.

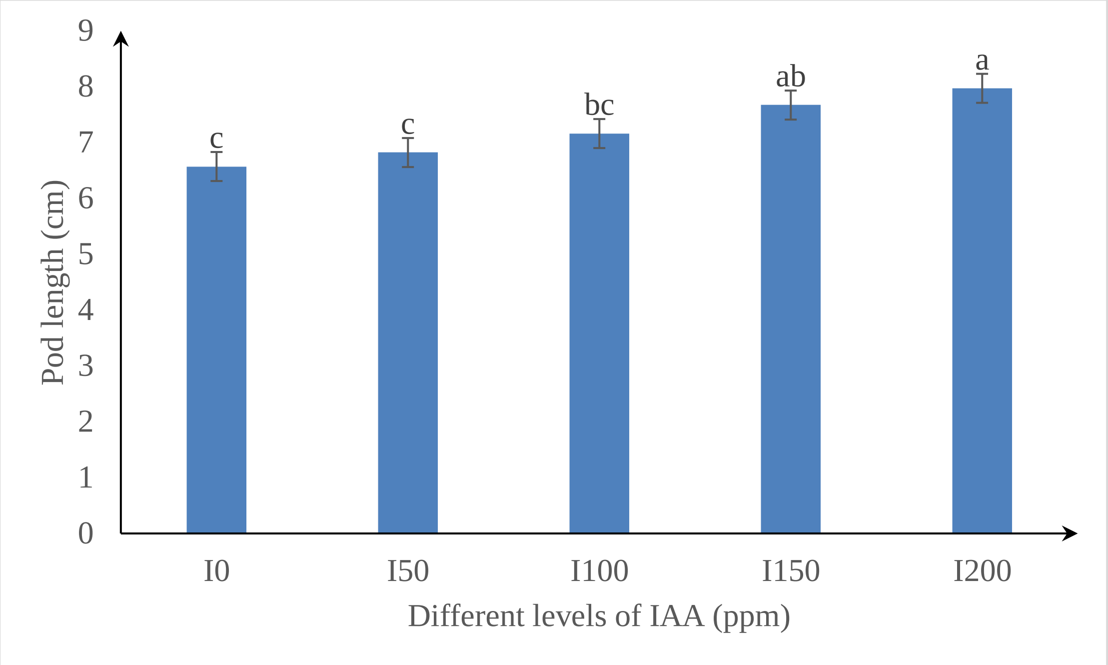


[Here, W_0 = No water logging; W_e = Water logging at pod maturity stage]

Figure 11. Effect of water logging at pod maturity stage on pod length of mungbean [$LSD_{(0.05)}$ = 7.74]

4.7.2 Effect of IAA

In this experiment, effect of IAA on pod length (cm) of BARI Mung 6 was found significant (Fig. 12). Pod length was increased due to the application of IAA. The highest pod length (7.97 cm) was recorded in I_{200} (200 ppm IAA application). However, statistically identical result were found in I_{150} (150 ppm IAA application) (7.67 cm). On the other hand, plants without the application of IAA (control treatment A1) gave lowest pod length (6.57 cm) (Figure 12). Saha *et al*. (1996) reported that 300, 600 and 900 ppm IAA applied at the beginning of the tillering stage in wheat increased ear, spikelet and grain length. Sanyal *et al.* (1995) mentioned similar results for tomato.



[Here, I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition]

Figure 12. Effect of IAA on pod length of mungbean [$LSD_{(0.05)}$ = 0.61]

4.7.3 Interaction effect of water logging and IAA

In this experiment significant interaction effect of water logging and IAA was observed on pod length (cm) for BARI Mung 6 (Table 7). The maximum pod length (8.64 cm) was recorded in W_0I_{200} (no water logging condition with application of 200 ppm IAA) treatment combination which was statistically identical with W_0I_{150} (no water logging condition with application of 150 ppm) (8.26 c,) and followed by W_0I_{100} (7.68 cm). On the other hand, the minimum pod length (6.18 cm) was recorded in W_eI_0 (water logging condition with no application of IAA) treatment combination which was statistically similar with W_eI_{50} (water logging condition with application of 50 ppm IAA) (6.45 cm), W_eI_{100} (water logging condition with application of 100 ppm IAA) (6.64 cm) and W_eI_{150} (water logging condition with application of 150 ppm IAA) (7.08 cm).

Table 7. Interaction effect of water logging at pod maturity stage and different level of IAA on pod number plant^{-1} and pod length (cm) of mungbean

Interaction	Pods Plant^{-1} (no.)	Pod length (cm)
W_0I_0	9.84 de	6.96 c-e
W_0I_{50}	11.05 d	7.18 cd
W_0I_{100}	13.36 c	7.68 bc
W_0I_{150}	16.31 b	8.26 ab
W_0I_{200}	17.77 a	8.64 a
W_eI_0	8.17 f	6.18 e
W_eI_{50}	8.90 ef	6.45 de
W_eI_{100}	9.55 e	6.64 de
W_eI_{150}	9.82 de	7.08 cd
W_eI_{200}	9.99 de	7.31 cd
$LSD_{(0.05)}$	1.24	0.86
CV (%)	7.49	8.22

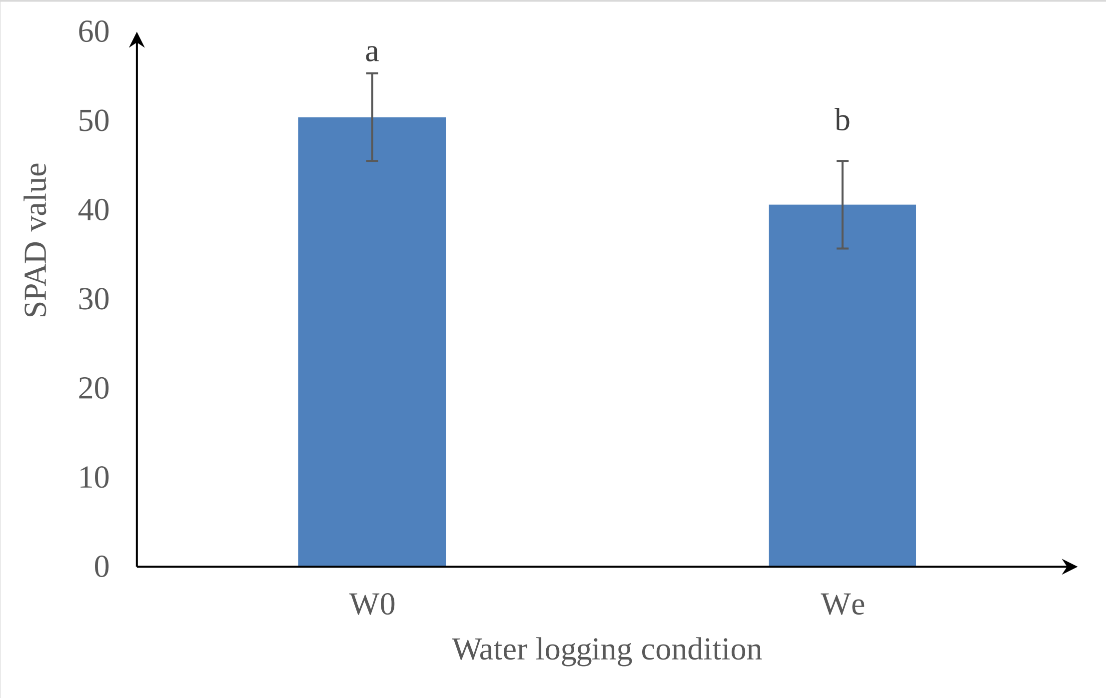
In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

[Here, W_0 = No water logging; W_e = Water logging at pod maturity stage; I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition]

4.8 SPAD value

4.8.1 Effect of water logging

The effect of water logging on chlorophyll content was statistically significant in mungbean (Fig. 13). Higher chlorophyll was found in 50.43 (SPAD unit) in which measured in control condition and lower amount of chlorophyll was contained 40.6 (SPAD unit) in waterlogging condition and all the measured chlorophyll contained data were reduced in waterlogging than control. Photosynthesis is one of the most important physiological mechanism. (Ramachandra *et al.*, 2004). In this experiment, SPAD value was decreased due to waterlogging stress. Waterlogging in soybeans showed a decrease in photosynthetic activity (Mutava *et al.*, 2015). Tian *et al.* (2019b) showed that SPAD value reduced 10-38% in KY16 variety and 5-30% in DMY1 variety of maize due to waterlogging. Previous studies recorded that waterlogging reduced the Chl content as a result of the reduction of photosynthetic activity and rate, which decline plant development and biomass accumulation. It has been found that waterlogging remarkably decreased N uptake in soybean leaves and branches. The results of prolonged waterlogging CO_2 assimilation declined, which caused the reduction of photosynthesis (Yordanova and Popova, 2007)



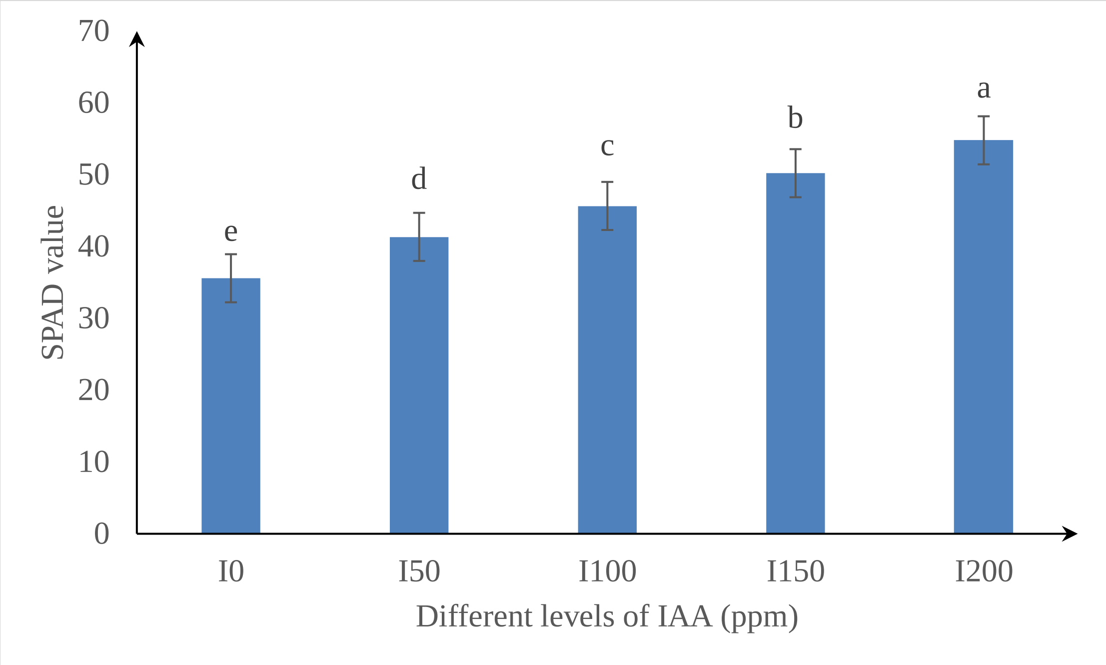
[Here, W_0 = No water logging; W_e = Water logging at pod maturity stage]

Figure 13. Effect of water logging at pod maturity stage on SPAD value of mungbean [$LSD_{(0.05)}$ = 1.05]

4.8.2 Effect of IAA

In this experiment, effect of IAA on SPAD value of BARI Mung 6 was found statistically significant (Fig. 14). SPAD value was increased due to the application of

IAA. The highest SPAD value (54.79) was recorded in I_{200} (200 ppm IAA application). On the other hand, plants without the application of IAA (control treatment A1) gave lowest SPAD value (35.58). Muthulakshmi and Pandiyarajan (2015) said that application of IAA led to significant increase photosynthetic pigment, non-photosynthetic pigment composition leaf nitrate, chlorophyll content.



[Here, I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition]

Figure 14. Effect of IAA on SPAD value of mungbean [$LSD_{(0.05)}$ = 1.65]

4.8.3 Interaction effect of water logging and IAA

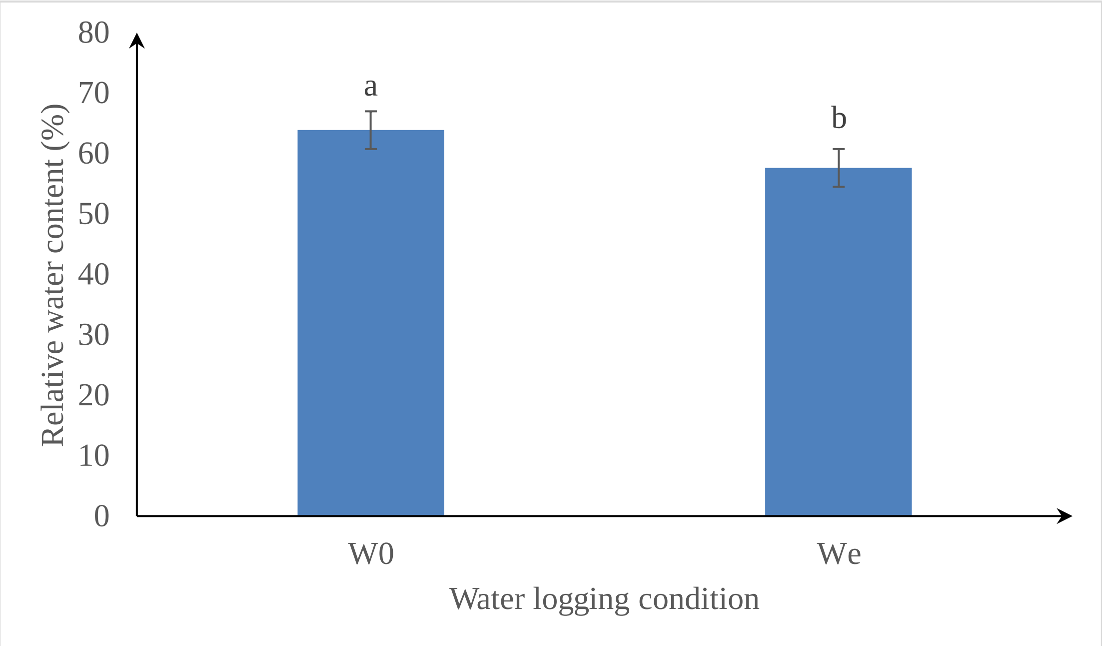
In this experiment significant interaction effect of water logging and IAA was observed on SPAD value for BARI Mung 6 (Table 8). The maximum SPAD value (58.57) was recorded in W_0I_{200} (no water logging condition with application of 200 ppm IAA) treatment combination followed by W_0I_{150} (no water logging condition with application of 150 ppm) (55.22,) and W_0I_{100} (51.15). On the other hand, the minimum SPAD value (31.12) was recorded in W_eI_0 (water logging condition with no application of IAA) treatment combination followed by W_eI_{50} (water logging condition with application of

50 ppm IAA) (35.51), W_eI_{100} (water logging condition with application of 100 ppm IAA) (40.15) and W_0I_0 (no water stress condition with no application of IAA) (40.04).

4.9 Relative water content (RWC)

4.9.1 Effect of water logging

The effect of water logging on relative water content (RWC) was statistically significant in mungbean (Fig. 15). Higher relative water content (RWC) was found in 63.86 in which measured in control condition and lower amount of relative water content (RWC)l was contained 57.61 in waterlogging condition and all the measured relative water content (RWC) contained data were reduced in waterlogging than control. Reduction in leaf RWC suggests an insufficient supply of water for cell expansion. Despite the excess quantity of water available under waterlogged conditions, RWC were reduced of mungbean plants. This may be occurred due to domination of waterlogging, which hampered root permeability (Asharf, 2012) and as a result, leaf wilting symptoms were observed on plants. Similar results found in different plants by (Anee *et al.*, 2019; Kumar *et al.*, 2013).

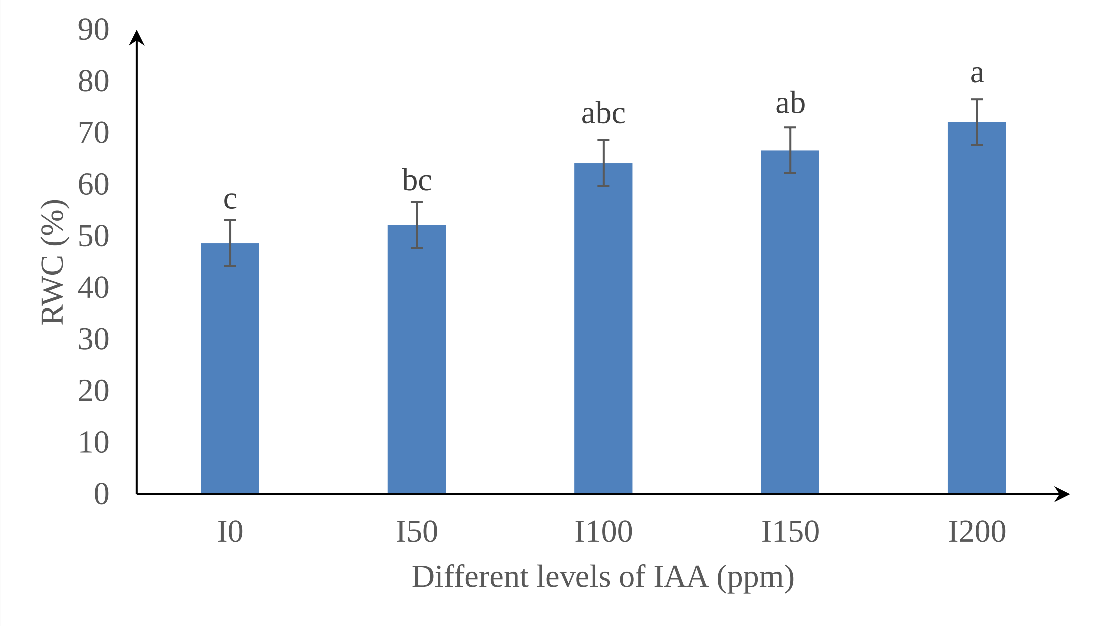


[Here, W_0 = No water logging; W_e = Water logging at pod maturity stage]

Figure 15. Effect of water logging at pod maturity stage on RWC value of mungbean [$LSD_{(0.05)}$ = 10.04]

4.9.2 Effect of IAA

In this experiment, effect of IAA on relative water content (RWC) value of BARI Mung 6 was found statistically significant (Fig. 16). Relative water content (RWC) value was increased due to the application of IAA. The highest SPAD value (72.07) was recorded in I_{200} (200 ppm IAA application). On the other hand, plants without the application of IAA (control treatment A1) gave lowest relative water content (RWC) value (52.17) (Figure 16).



[Here, I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition]

Figure 16. Effect of IAA on relative water content (RWC) of mungbean [$LSD_{(0.05)}$ = 15.87]

4.9.3 Interaction effect of water logging and IAA

In this experiment significant interaction effect of water logging and IAA was observed on relative water content (RWC) value for BARI Mung 6 (Table 8). The maximum relative water content (RWC) value (76.76) was recorded in W_0I_{200} (no water logging condition with application of 200 ppm IAA) treatment combination which was statistically at par with W_0I_{150} (no water logging condition with application of 150 ppm)

(68.70,) and W_0I_{100} (67.37). On the other hand, the minimum relative water content (RWC) value (38.74) was recorded in W_eI_0 (water logging condition with no application of IAA) treatment combination followed by W_eI_{50} (water logging condition with application of 50 ppm IAA) (41.15).

Table 8. Interaction effect of water logging at pod maturity stage and different level of IAA on SPAD value and RWC of mungbean

Interaction	SPAD value	RWC
W_0I_0	40.04 e	63.19 a-c
W_0I_{50}	47.17 d	65.59 ab
W_0I_{100}	51.15 c	67.37 a
W_0I_{150}	55.22 b	68.70 a
W_0I_{200}	58.57 a	76.76 a
W_eI_0	31.12 g	38.74 c
W_eI_{50}	35.51 f	41.15 bc
W_eI_{100}	40.15 e	58.55 a-c
W_eI_{150}	45.19 d	62.70 a-c
W_eI_{200}	51.01 c	64.58 ab
$LSD_{(0.05)}$	2.34	22.44
CV (%)	3.55	25.59

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

[Here, W_0 = No water logging; W_e = Water logging at pod maturity stage; I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition]

4.10. 1000 seed weight (g)

4.10.1 Effect of water logging

Statistically significant variation was observed in case of different water logging treatments for 1000 seed weight of mungbean (Table 9). The highest 1000 seed weight (39.17 g) was recorded from W_0 (control i.e. no water logging) whereas the lowest 1000 seed weight (32.03 g) was recorded from W_e (Water logging at pod maturity stage).

1000-seed weight gradually decreasing trend in response to an increase in the duration of waterlogging in soybean (Miao *et al.,* 2012; Beutler *et al.,* 2014). Similar results were observed in some other crops like maize (Tian *et al.,* 2019b), wheat and barley (De San Celedonio *et al.,* 2014). Waterlogging reduced shoot length, biomass, photosynthesis and pod formation and ultimate result is lower yield.

4.10.2 Effect of IAA

Significant variation was found for different levels of IAA on 1000 seed weight of mungbean (Table 9). The highest 100 seed weight (43.20 g) was found from I_{200} (200 ppm IAA application) followed by I_{150} (39.37 g) whereas the minimum 1000 seed weight (28.26 g) was recorded from I_0 (No IAA application) which was statistically different from all other treatments and followed by I_{50} (31.34 g). Saha *et al.* (1996) reported that 300, 600 and 900 ppm 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); Gurdev and Saxena (1991) and Rahman *et al.* (1989).

4.10.3 Interaction effect of waterlogging and IAA

In this experiment significant interaction effect of water logging and IAA was observed on 1000 seed weight for BARI Mung 6 (Table 10). The highest 1000 seed weight (49.57 g) was recorded in W_0I_{200} (no water logging condition with application of 200 ppm IAA) treatment combination which was statistically identical from all other treatment and followed by W_0I_{150} (43.90 g). On the other hand, the lowest 100 seed weight (26.82 g) was recorded in W_eI_0 (water logging condition with no application of IAA) treatment combination which was statistically identical with W_0I_{50} (27.83 g).

4.11 Yield per plant (g)

4.11.1 Effect of water logging

Statistically significant variation was observed in case of different water logging treatments for yield of mungbean per plant (Table 9). The highest yield per plant (12.92 g) was recorded from W_0 (control i.e. no water logging) whereas the lowest yield per plant (9.75 g) was recorded from W_e (Water logging at pod maturity stage). From the finding it was revealed that waterlogging decreased the seed yield significantly over the control. Reduction in seed yield was fundamentally due to diminish of water absorbing ability of the plants as specified by the reduction in leaf turgidity as well as translocation of dry matter from the vegetative growth to the reproductive structures (seeds) possibly due to damage caused to the root system. Such inhibition may also be due to adverse effects of waterlogging on water and mineral uptake (Hook *et al.,* 1993). Reduction in seed yield was mainly due to impairment of water absorbing ability of the plants or inhibition of synthesis and transportation of photosynthetic assimilate (Kumar *et al.,* 2013).

4.11.2 Effect of IAA

Significant variation was found for different levels of IAA on yield of mungbean plant (Table 9). The highest yield per plant weight (14.75 g) was found from I_{200} (200 ppm IAA application) followed by I_{150} (13.01 g) whereas the minimum yield per plant weight (8.11 g) was recorded from I_0 (No IAA application) which was statistically different from all other treatments and followed by I_{50} (9.64 g).

4.11.3 Interaction effect of waterlogging and IAA

In this experiment significant interaction effect of water logging and IAA was observed on yield per plant for BARI Mung 6 (Table 10). The highest yield per plant (17.43 g) was recorded in W_0I_{200} (no water logging condition with application of 200 ppm IAA) treatment combination followed by W_0I_{150} (14.83 g). On the other hand, the lowest yield per plant (6.74 g) was recorded in W_eI_0 (water logging condition with no application of IAA) treatment combination followed by W_0I_{50} (8.78 g).

Table 9. Effect of water logging at pod maturity stage and IAA on 1000 seed weight (g) and yield per plant of mungbean

Factors	1000 seeds weight (g)	Yield per plant (g)
Factors-A		
$\mathbf{W_0}$	39.17 a	12.92 a
$\mathbf{W_e}$	32.03 b	9.75 b
$\mathbf{LSD_{(0.05)}}$	1.49	0.55
CV (%)	6.48	7.53
Factor-B		
$\mathbf{I_0}$	28.26 e	8.11 e
$\mathbf{I_{50}}$	31.34 d	9.64 b
$\mathbf{I_{100}}$	35.85 c	11.13 c
$\mathbf{I_{150}}$	39.37 b	13.01 b
$\mathbf{I_{200}}$	43.20 a	14.75 a
$\mathbf{LSD_{(0.05)}}$	2.36	0.87
CV (%)	6.48	7.53

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

[Here, W_0 = No water logging; W_e = Water logging at pod maturity stage; I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition]

Table 10. Interaction effect of water logging at pod maturity stage and IAA on 1000 seed weight and yield per plant of mungbean

Interaction	1000 seeds weight (g)	Yield per plant (g)
W_0I_0	29.70 e	9.48 ef
W_0I_{50}	34.86 cd	10.50 de
W_0I_{100}	37.83 c	12.34 c
W_0I_{150}	43.90 b	14.83 b
W_0I_{200}	49.57 a	17.43 a
W_eI_0	26.82 e	6.74 g
W_eI_{50}	27.83 e	8.78 f
W_eI_{100}	33.86 d	9.92 ef
W_eI_{150}	34.83 cd	11.20 cd
W_eI_{200}	36.83 cd	12.07 c
$LSD_{(0.05)}$	3.33	1.23
CV (%)	6.48	7.53

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

[Here, W_0 = No water logging; W_e = Water logging at pod maturity stage; I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition]

CHAPTER V

SUMMARY AND CONCLUSION

A pot experiment was conducted in farm of Sher-e-Bangla Agricultural University, Dhaka during the period from April, 2022 to July, 2022 to find out the effect of IAA on mugnbean under water logging condition at pod maturity stage. The experiment comprised of two factors, where factor A comprised two level of water logging (W_0 = No water logging; W_e = Water logging at pod maturity stage) and factor B comprised of 5 level of IAA (I_0 = No IAA – only spray water (Control); I_{50} = Spray of IAA @ 50 ppm at 15 DAS and at 2 days after stress imposition; I_{100} = Spray of IAA @ 100 ppm at 15 DAS and at 2 days after stress imposition; I_{150} = Spray of IAA @ 150 ppm at 15 DAS and at 2 days after stress imposition and I_{200} = Spray of IAA @ 200 ppm at 15 DAS and at 2 days after stress imposition). The experiment was laid out in Completely Randomized Design (CRD) with four replications.

Data were collected on phenological parameters, crop growth parameters, physiological parameters, yield and yield contributing characters. Data were analyzed and the mean value was adjudged with Least Significant Difference (LSD).

The study revealed that at maturity stage, waterlogging showed remarkable decrease of plant height, branch number plant^{-1}, above ground fresh weight plant^{-1}, above ground dry weight plant^{-1}, pod length, number of pod plant^{-1}, SPAD value, relative water content, 1000 seed weight and yield plant^{-1}. Beside this, it also delayed the days of maturity compare to control.

On the other hand, application IAA @ 200 ppm produced the tallest plant at 15, 30, 45, 60 DAS and at harvest (14.42 cm, 20.91 cm, 34.54 cm, 44.88 cm and 50.60 cm respectively); maximum number of branches plant^{-1} at 15, 30, 45, 60 DAS and at harvest (4.55, 10.1, 11.77, 13.09 and 14.18 respectively); early flowering (39.75 days); early maturity (56.63 days); maximum above ground fresh weight and dry weight of plant^{-1} (10.52 g and 8.63 g, respectively), maximum pod number per plant (13.88); highest SPAD and RWC value (50.43 and 72.07, respectively), 1000 seed weight (39.17 g) and yield plant^{-1} (12.92 g).

In most cases, the interaction effect between water logging and application of IAA at different levels was significant. The tallest plant at 15, 30, 45, 60 DAS and at harvest (15.08 cm, 22.04 cm, 36.45 cm, 46.79 cm and 52.36 cm, respectively); highest number of branches plant^{-1} at 15, 30, 45, 60 DAS and at harvest (4.90, 10.41, 12.08, 13.53 and 13.80, respectively); early flowering (38.25 days); early maturity (53.75 days); maximum above ground fresh weight and dry weight of plant^{-1} (11.47 g and 9.76 g, respectively), highest number of pod plant^{-1} (17.77); longest pod (8.64 cm); highest SPAD and RWC value (54.79 and 76.76); 1000 seed weight (49.57 g) and yield plant^{-1} (17.43 g) was found in no water logging condition with application of IAA @ 200 ppm.

From the above finding it can be concluded that the ability of IAA to revert the harmful effects of waterlogging on mungbean and increased yield by improving all parameters. To ensure optimal growth and yield in mungbean cultivation, maintain proper field drainage to prevent waterlogging at maturity stage and apply IAA at a concentration of 200 ppm, which has been shown to not only counteract the detrimental effects of waterlogging but also enhance plant height, branch number, pod count, and overall productivity. For determination of accuracy of the results and effectiveness of IAA application, further trail should be performed in different locations for conformation.

REFERENCES

Abd El-Aal, M. M. M. and Rania, S. M. E. (2018). Effect of foliar spray with lithovit and amino acids on growth, bioconstituents, anatomical and yield features of soybean plant. 4th International Conference on Biotechnology Applications in Agriculture (ICBAA), Benha University, Moshtohor and Hurghada, 4-7 April 2018, Egypt. pp. 187-202.

Abdel, G. B. A., Shourbagy M. N. E. and Naggar, R. A. (1996). Effect of IAA and GA3 on flax (*Linum usitatissium* L.) seed yield and their metabolic constituents. *Egyptian J. Bot.* **35**(1): 1-9.

Abel, S. and Theologis, A. (2010). Odyssey of auxin. Perspective in biology; Cold Spring Harbor Press, Leibniz-Institut Fuer, Germany, pp. 1-13.

Ahmad, R., Ikraam, M., Ullah, E. and Mahmood, A. (2003). Influence of different fertilizer levels on the growth and productivity of three mungbean cultivars. *Intl. J. Agric. Biol.* **5**: 335–338.

Ahmed, S., Higuchi, H., Nawata, E., and Sakuratani, T. (2002). Effects on exogenous ABA and ethylene application and waterlogging on photosynthesis in Mungbean (*Vigna radiata* (L.) Wilczak). *Japan J. Trop. Agric.* **46**: 166–174.

Akhtar, I. and Nazir, N. (2013). Effect of waterlogging and drought stress in plants. *Intl. J. Water Resour. Environ. Sci.* **2**: 34-40.

Amanullah, M. M., Sekar, S. and Vincent, S. (2010). Plant growth substances in crop production: A review. *Asian J. Pl. Sci.* **9**: 215-222.

Amin, M. R., Karim, M. A., Islam, M. R., Aktar, S. and Hossain, M. A. (2016). Effect of flooding on growth and yield of mungbean genotypes. *Bangladesh J. Agril. Res.* **41**(1): 151-162.

Anee, T. I., Nahar, K., Rahman, A., Al Mahmud, J., Bhuiyan, T. F., Alam, M. U., Fujita, M. and Hasanuzzaman, M. (2019). Oxidative damage and antioxidant defense in Sesamum indicum after different waterlogging durations. *Plants.* **8**: 196.

Anonymous. (1988a). The Year Book of Production. FAO, Rome, Italy.

Anonymous. (1988b). Land resources appraisal of Bangladesh for agricultural development. Report No. 2. Agro-ecological regions of Bangladesh, UNDP and FAO. pp. 472–496.

Antheunisse, A. M. and Verhoeven, J. T. A. (2008). Short term responses of soil nutrient dynamics and herbaceous riverine plant communities to summer inundation. *Wetland*. **28**: 232-244.

Arora, N., Kaur. B., Singh, P. and Paramar, U. (1998). Effect of IAA and Cycocel on yield contributing parameters of chickpea (*Cicer arietinum* L.). *Agril. Res.* **19**(3): 279-281.

Ashraf, M. A. (2012). Waterlogging stress in plants: A review. *African. J. Agric. Res.* 7(13): 1976-1981.

Bailey-Serres. J. and Voesenek, L. A. C. J. (2008). Flooding stress: acclimations and genetic diversity. *Annu. Rev. Pl. Biol.* **160**: 1698-709.

BBS (Bangladesh Bureau of Statistics) (2022). Year Book of Agricultural Statistics of Bangladesh, 2020-21. Statistics Division, Ministry of Planning, Dhaka. pp: 109.

Bellini, C., Pacurar, D. I. and Perrone, I. (2014). Adventitious roots and lateral roots: simi- larities and diferences. *Annu. Rev. Pl. Biol.* **65**: 639–666.

Beutler, A. N., Giacomeli, R., Alberto, C. M., Silva, V. N., Da Silva Neto, G. F., Machado, G. A. and Santos, A. T. L. (2014). Soil hydric excess and soybean yield and development in Brazil. *Aust. J. Crop Sci.* **8**(10): 1461-1466.

Bora, R. K. and Sarma, C. M., (2006). Effect of Gibberellic acid and cycocel on growth, yield and protein content of pea. *Asian J. Pl. Sci.* **5**: 324-330.

Casimiro, I., Beeckman, T., Graham, N., Bhalerao, R., Zhang, H.M., Casero, P., Sandberg, G. and Bennett, M. J. (2003). Dissecting Arabidopsis lateral root development. *Trends Pl. Sci.* **8**: 165–171.

Celik, G. and Turhan, E. (2011). Genotypic variation in growth and physiological responses of common bean (*Phaseolus vulgaris* L.) seedlings to flooding. *African. J. Biot.* **10**:7372– 7380.

Chellappa, M. and Karivaratharaju, T. V. (1973). Effect of pre-sowing treatment with phytohormones on the yield of *Arachis hypogaea* L. *Physiol. Abst.* **2**(2): 69.

Chotechuen, S. (1996). Breeding of mungbean for resistance to various environmental stresses. In: Proceedings of the workshop on mungbean germplasm. Bangkok.

Davies, P. J. (2004). Plant Hormones: Biosynthesis, Signal Transduction, Action. 3rd Edn., Kluwer Academic Press, The Netherlands, ISBN: 1402026854, Pp: 750.

De San Celedonio, R. P., Abeledo, L. G. and Miralles, D. J. (2014). Identifying the critical period for waterlogging on yield and its components in wheat and barley. *Pl. Soil*. **378**: 265-277.

De Smet, I., Vanneste, S., Inzé, D. and Beeckman, T. (2006). Lateral root initiation or the birth of a new meristem. *Pl. Mole. Bio.* **60**: 871-887.

El-Karamany, F. M. (2006). Double purpose (forage and seed) of mungbean production 1-effect of plant density and forage cutting date on forage and seed yields of mungbean (*Vigna radiate* (L.) Wilczck). *Res. J. Agric. Biol. Sci.* **2**: 162-165.

Elshorbagi, M., Bahia, A., Ghaffar, A., El-Naggar, R.A. (2008). Effect of IAA and GA_3 on the anatomical characteristics, stover and fiber yield and quality of Flax. *J. Agron. Crop Sci.* **174**(1): 21-26.

Fakir, M. S. A., Mondal, M. M. A., Ismail, M. R. and Ashrafuzzaman, M. (2011). Flowering pattern and reproductive efficiency in mungbean. *Intl. J. Agric. Biol.* **13**: 966-970.

FAO (Food and Agriculture Organization) (2011). FAO Statistical Year Book of 2011. World Food and Agriculture. Food and Agriculture Organization (FAO), Rome, Italy.

Fukaki, H., Okushima, Y. and Tasaka, M. (2007). Auxin-mediated lateral root formation in higher plants. International Review of Cytology – a Survey of Cell Biology. **256**: 111–137.

Gomez, K. A. and Gomez, A. A. (1984). Statistical Procedure for Agricultural Research (2nd edn.). Intl. Rice Res. Inst., A Willey Int. Sci., pp. 28-192.

Gou, J., Strauss, S. H., Tsai, C. J., Fang, K., Chen, Y., Jiang, X. and Busov, V. B. (2010). Gibberellins regulate lateral root formation in Populus through interactions with Auxin and other hormones. *Pl. Cell.* **22**: 623-639.

Grazesiak, S., Koscielniak, J., Filek, W. and Augustyniak, G. (1989). Effects of soil drought on the generative phase of development of field bean, (*Vicia faba* L. var. minor) on leaf water status, photosynthesis rate and biomass growth. *J. Agron. crop Sci.* **162**: 241- 247.

Gurdev, S. and Saxena, O. P. (1991). Seed treatments with bioregulators in relation to wheat productivity. New tread in plant physiology, proceeding, National Symposium on growth and differentiation in plants. New Delhi, India. pp. 201-210.

Hamid, A., Agata, W., Moniruzzaman, A. F. M. and Miah, A. A. (1991). Physiological aspects of yield improvement in Mungbean. Proc. of the Second National Workshop on Pulses, 6- 8 Jan, 1989, BARI, Gazipur (Bangladesh), pp. 87-94.

Himanen, K., Vuylsteke, M., Vanneste, S., Vercruysse, S., Boucheron, E., Alard, P., Chriqui, D., Van Montagu, M., Inzé, D. and Beeckman, T. (2004). Transcript profiling of early lateral root initiation. *Proc. Natl. Acad. Sci.* USA **101**(14): 5146-51.

Hook, D. D., Crawford, R. M. M., Gardner, W. K. and Flood, R.G. (1993). Less waterlogging damage with long season wheats. *Cereal Res. Commun.* **21**(4): 337-343.

Hussain, K., Hussain, M., Majeed, A., Nawaz, K., Nisar, M.F. and Afghan, S. (2010). Morphological response of scurf pea (*Psoralea corylifolia* L.) to indole acetic acid (IAA) and nitrogen (N). *World Appl. Sci. J.* **8**: 1220-1225.

Islam, M. O., Rahim, M. A. and Prodhan, A. K. M. A. (2010). Flowering pattern, floral abscission and yield attributes in soybean influenced by GABA. *J. Bangladesh Agri. Univ.* **8**(1): 29-33.

Izquierdo, J. A. and Hosfield, G. L. (1981). A Collection Receptacle for Field Abscission Studies in Common Bean. *Crop Sci.* **21**: 622-625.

Jannat, O. (2020). Short term water logging effect on mungbean. M. S. Thesis, Department of Agroforestry and Environment Science, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh, p: 65.

Jiang, Y. and Wang, K. (2006). Growth, physiological and anatomical responses of creeping bentgrass cultivars to different depths of waterlogging. *Crop Sci.* **46**(6): 2420-2426.

Khalil, S. and Mandurah, H. M. (1989). Growth and metabolic changes of cowpea plants as affected by water deficiency and Indole Acetic Acid. *J. Agron. Crop Sci.* **165**(3): 160-166.

Koyama, T., Suenaga, M. and Takeshima, R. (2019). Growth and yield response of common buckwheat (*Fagopyrum esculentum*) to waterlogging at different vegetative stages. *Pl. prod. Sci.* **22**(4): 456-464.

Kumar, P., Pal, M., Joshi, R. and Sairam, R. K. (2013). Yield, growth and physiological responses of mung bean [*Vigna radiata* (L.) Wilczek] genotypes to waterlogging at vegetative stage. *Physiol. Mol. Biol. Plants.* **19**: 209-220.

Kumutha, D., Ezhilmathi, K., Sairam, R. K., Srivastava, G. C., Deshmukh, P. S. and Meena, R. C. (2009). Waterlogging induced oxidative stress and antioxidant activity in pigeon pea genotypes. *Biol. Pl.*. **53**(3): 75-84.

Kyu, K. L., Malik, A. I., Colmer, T. D. Siddique, K. H. M. and Erskine, W. (2021). Response of Mungbean (cvs. Celera II-AU and Jade-AU) and Blackgram (cv. Onyx-AU) to Transient Waterlogging. *Frontiers Pl. Sci.* **12**: 121-125. doi: 10.3389/fpls.2021.709102

Lamers, L. P. M., Loeb, R., Antheunisse, A. M., Miletto, M., Lucassen, E. C. H. E. T., Boxman, A. W., Smolders, A. J. P. and Roelofs, J. G. M. (2006). Biogeochemical constraints on the ecological rehabilitation of river floodplains. *Hydrobiologia.* **565**: 165-186.

Lee, H. S. (1990). Effects of pre-sowing seed treatments with GA_3 and IAA on flowering and yield components in groundnuts. *Korean J. Crop Sci.* **35**(1): 1- 9.

Li, X., Zeng, R. and Liao, H. (2015). Improving crop nutrient efficiency through root architecture modifications. *J. Integr. Pl. Biol.* **58**: 193-202.

Lim, P. O., Woo, H. R. and Nam, H. G. (2003). Molecular genetics of leaves senescence in Arabidopsis. *Trends Pl. Sci.* **8**: 272-278.

Malik, M. F. A., Qureshi, A. S., Ashraf, M. and Ghafoor, A. (2006). Genetic variability of the main yield related characters in soybean. *Intl. J. Agril. Biol.* **8**: 815-819.

Manikandan, R. and Hakim, S.A. (1998). Effect of IAA and parthenium crude extract on black gram and groundnut. *Adv. Pl. Sci*. **12**(2): 345-348.

Mathur, M. M. (1971). Response of *Allium cepa* L. transplants to different plant growth regulators. *Indian J. Hort.* **28**(4): 296-300.

Matsunami, T., Jung, G.H., Oki, Y., Zhang, W.H. and Kokubun, M. (2005). Effects of waterlogging on nitrogen fixation of a supernodulating soybean genotype. In: Biological nitrogen fixation, sustainable agriculture and the environment. Netherlands: Springer; pp. 283–284.

Miao, S., Shi, H., Jian, J., Judong, L., Xiaobing, L. and Guanghua, W. (2012). Effects of short-term drought and flooding on soybean nodulation and yield at key nodulation stage under pot culture. *J. Food Agric. Environ.* **10**: 819–824.

Miransari, M. (2014). Plant growth promoting rhizobacteria. *J. Pl. Nutr.* **37**: 2227-2235.

Mondal, M. E. A., Rahman, H., Rashid, M. H., Hossain, M. A. and Islam, M. M. (2013). Screening of mungbean germplasm for resistance to mungbean yellow mosaic virus. *Intl. J. Sus. Crop Pro.* **8**(1): 11-15.

Mondal, M. M. A. (2007). A study of source-sink relation in mungbean. Ph.D Dissertation, Department of Crop Botany, Bangladesh Agricultural University, Mymensingh, Bangladesh, p: 46.

Mondal, M. M. A., Fakir, M. S. A., Abdul, S. J., Hakim, M. A., Islam, M. M. and Shamsuddoha A. T. M. (2011). Effects of flowering behavior and pod maturity synchrony on yield of mungbean [*Vigna radiata* (L.) Wilczek]: *AJCS.* **5**(8):945-953.

Munir, A., Anwar-ul-Hassan, Nawaz, S. and Bajwa, M. A. (2012). Farm manure improved soil fertility in mungbean-wheat cropping system and rectified the deleterious effects of brackish water. *Pakistan. J. Agric. Sci.* **49**: 511–519.

Mustafa, G. and Komatsu, S. (2014). Quantitative proteomics reveals the effects of protein glycosylation in soybean root under flooding stress. *Front. Pl. Sci.* **18**: 627.

Mutava, R. N., Prince, S. J. K., Syed, N. H., Song, L., Valliyodan, B., Chen, W. and Nguyen, H. T., (2015). Understanding abiotic stress tolerance mechanisms in soybean: a comparative evaluation of soybean response to drought and flooding stress. *Pl. Physiol. Biochem*. **86**: 109–120.

Muthulakshmi, S. and Pandiyarajan, V. (2015). Effect of IAA on the Growth, Physiological and Biochemical Characteristics in *Catharanthus roseus* (L). G. Don. *Intl. J. Sci. Res*. **4**(3): 442-448.

Naeem, M., Ahmed, R. H. and Ashraf, M. Y. (2004). Effect of some growth plant growth regulators (GA_3, IAA and kinetin) on the morphology and early or delayed initiation of bud of lentil (*Lens culinaris* medik). *Pakistan. J. Bot.* **36**(4): 801-809.

Newaj, M. N., Hossain, M. S., Islam, M. N., Anam, M. K. and Haque, A. H. M. M. (2002). Effect of Indoleacetic Acid (IAA) on yield of Mungbean (*Vigna radiata* L.). *J. Bio. Sci.* **5**(9): 897-899.

Palta, J.A., Ganjeali, A., Turner, N.C. and Siddique, K.H.M. (2010). Effects of transient subsurface waterlogging on root growth, plant biomass and yield of chickpea. *Agric. Water Manag*. **97**:1469–1476.

Paltaa, J. A., Ganjealic, A., Turnerb, N. C. and Siddique, K. H. M. (2010). Effects of transient subsurface waterlogging on root growth, plant biomass and yield of chickpea. *Agric. Water Manag.* **97**: 1469–1476.

Pan. J., Sharif, R., Xu, X. and Chen, X. (2021). Mechanisms of waterlogging tolerance in plants: research progress and prospects. *Front Pl. Sci.* **11**: 627-631.

Parelle, J., Roudaut, J. P. and Ducrey, M. (2006). Light acclimation and photosynthetic response of beech (*Fagus sylvatica* L.) saplings under artificial shading or natural Mediterranean conditions. *Ann. For. Sci.* **63**: 257- 266.

Pociecha, E. Koscielniak, J. Filek, W. (2008). Effect of root flooding and stage of development on the growth and photosynthesis of field bean (*Vicia faba* L. minor). *Acta. Physiol. Plant.* **30**: 529-535.

Prasanna, Y. L. and Rao, G. R. (2014). Effect of waterlogging on growth and seed yield in greengram genotypes. *Intl. J. Food Agric. Vet. Sci.* **4**: 124-128.

Quaderi, R. S., Shah, M. A. I., Hossain, A. F. M. G. F., Hoque, M. M. and Haque, M. S. (2006). Influence of seed treatment with indole acetic acid on mungbean cultivation. *Intl. J. Bot.* **2**: 42-47.

Rahman, M. M., Islam, M. A. and Mondal, M. R. K. (1989). Effect of wave length of light and some phytohormones on the growth and yield of grasspea. *Bangladesh J. Agril. Res.* **14**(1); 19-23.

Ramachandra, R. A., Chaitanya, K. V. and Vivekanandan, M. (2004). Drought-induced responses of photosynthesis and antioxidant metabolismin higher plants. *J. Pl. Physiol.* **161**: 1189–1202.

Rastogi, A., Siddique, A., Mishra, B.K., Srivastava, M., Pandey, R., Misra, P., Singh, M. and Shukla, S. (2013). Effect of auxin and gibberellic acid on growth and yield components of linseed (*Linum usitatissimum* L). *Crop Breed. Appl. Biotech*.**13**: 136-143.

Ren, B. Z., Zhang, J. W., Dong, S. T., Liu, P. and Zhao, B. (2016). Effects of waterlogging on leaf mesophyll cell ultrastructure and photosynthetic characteristics of summer maize. *PLoS One.* **11**: e0161424. https://doi.org/10.1371/journal.pone.0161424

Sadak, M. S. h., Dawood, M. G., Bakry, B. A. and El-Karamany, M. F. (2013). Synergistic Effect of indole acetic acid and kinetin on performance, some biochemical constituents and yield of flababean plant grown under newly reclaimed sandy soil. *World J. Agri. Sci.* **9**: 335-344.

Saha, M. K., Biswas, B. K., Alam, M. S. and Halder, B. C. (1996). Response of wheat to different growth regulators. *Bangladesh J. Agri.* **21**: 21-26.

Sairam, R. K. (2013). Effect of moisture stress on physiological activities of two contrasting wheat genotypes. *Indian J. Exp. Biol.* **32**: 594-597.

Saitoh, K., Nishimura, K. and Kuroda, T. (2004). Characteristics of flowering and pod set in wild and cultivated types of soybean. *Pl. Prod. Sci.* **7**: 172-177.

Sanyal, D., Kar, P. L. and Longkumar, M. (1995). Effect of growth regulator on physiochemical composition of tomato. *Adv. Hort. forest.* **4**: 67-71.

Shah, S. (2007). Effect of kinetin spray on growth and productivity of black cumin plants. *Russian J. Pl. Physiol.* **54**: 702-705.

Singh, D. P. and Singh, B. B. (2011). Breeding for tolerance to abiotic stresses in mungbean. *J. Food Legumes.* **24**(2): 83-90.

Solaiman, Z., Colmer, T.D., Loss, S.P., Thomson, B.D. and Siddique, K.H.M. (2007). Growth responses of cool-season grain legumes to transient waterlogging. *Australia. J. Agric. Res.* **58**: 406–412.

Somta, P. and Srinives, P. (2007). Genome research in mungbean [*Vigna radiata* (L.) Wilczek] and blackgram [*V. mungo* (L.) Hepper]. *Sci. Asia.* **33**: 69-74. doi: 10.2306/scienceasia1513-1874.2007.33(s1)0.069

Sontakey, P. Y., Belsore, W. V., Delotale, R. D., Takzure, S. C. and Wankhede, S. Z. (1991). Relative influence of growth hormones on growth and yield performance of sesame (*Sesamum indicum* L.). *New Agriculturist.***1**(2): 207-208.

Stefens, B. and Rasmussen, A. (2016). The physiology of adventitious roots. *Pl. Physiol*. **223**: 604-612.

Taiz, L. and Zeiger, E. (2006). Plant Physiology. 4th Edn., Sinauer Associates Inc. Publishers, Sunderland, Massachusetts, ISBN-10: 0-87893-856-7, pp: 764.

Tian, L., Bi, W., Liu, X., Sun, L. And Li, J. (2019a). Effects of waterlogging stress on the physiological response and grain-flling characteristics of spring maize (*Zea mays* L.) under field conditions. *Acta. Physiol. Pl.* **41**(63): 2−14.

Tian, L., Li, J., Bia, W., Zuoa, S., Lia, L., Lia, W. and Sunb, L. (2019b). Effects of waterlogging stress at different growth stages on the photosynthetic characteristics and grain yield of spring maize (*Zea mays* L.) Under field conditions. *Agric. Water Manag.* **218**: 250-258.

Tian, L., Zhang, Y., Chen, P., Zhang, F., Li, J. and Yan, F. (2021). How does the waterlogging regime affect crop yield? A global meta-analysis. *Front Pl. Sci.* **12**: 634-638.

Ullah, M. J. (2006). Effect of water logging on growth and yield of mungbean cv. Kanti (*Vigna radiata*). *Legume Res.* **29**(3): 196-200.

Umaharan, P., Ariyanayagam, R.P. and Haque, S.Q. (1997). Effect of short-term waterlogging applied at various growth phases on growth, development and yield in *Vigna unguiculata*. *J Agric Sci*. **128**: 189–198.

Vanneste, S., Rybel, B., Beemster, G. T., Ljung, K., Smet, I., Van, I. G., Naudts, M., Iida, R., Gruissem, W., Tasaka, M. (2005) Cell cycle progression in the pericycle is not sufficient for SOLITARY ROOT/IAA14-mediated lateral root initiation in *Arabidopsis thaliana. Pl. Cell.* **17**: 3035–3050.

Wollmer, A. C., Pitann, B. and Mühling, K. H. (2019). Timing of waterlogging is crucial for the development of micronutrient deficiencies or toxicities in winter wheat and rapeseed. *J. Pl. Growth Regul.* **38**: 824-830.

Yamauchi, T., Watanabe, K., Fukazawa, A., Mori, H., Kawaquchi, K., Oyanagi, A. and Nakazono, M. (2014). Ethylene and reactive oxygen species are involved in root aerenchyma formation and adaptation of wheat seedlings to oxygendeficient conditions. *J. Exp. Bot.* **65**: 261-273.

Yan, L., Guo, W., Feng, C., Reng, Y., Zhu, X., Zhu, Z. and Zhang, Y. (1995). Studies on the grain volume and degree of filling in wheat. *Acta Agron Sci.* **21**(5): 637-640.

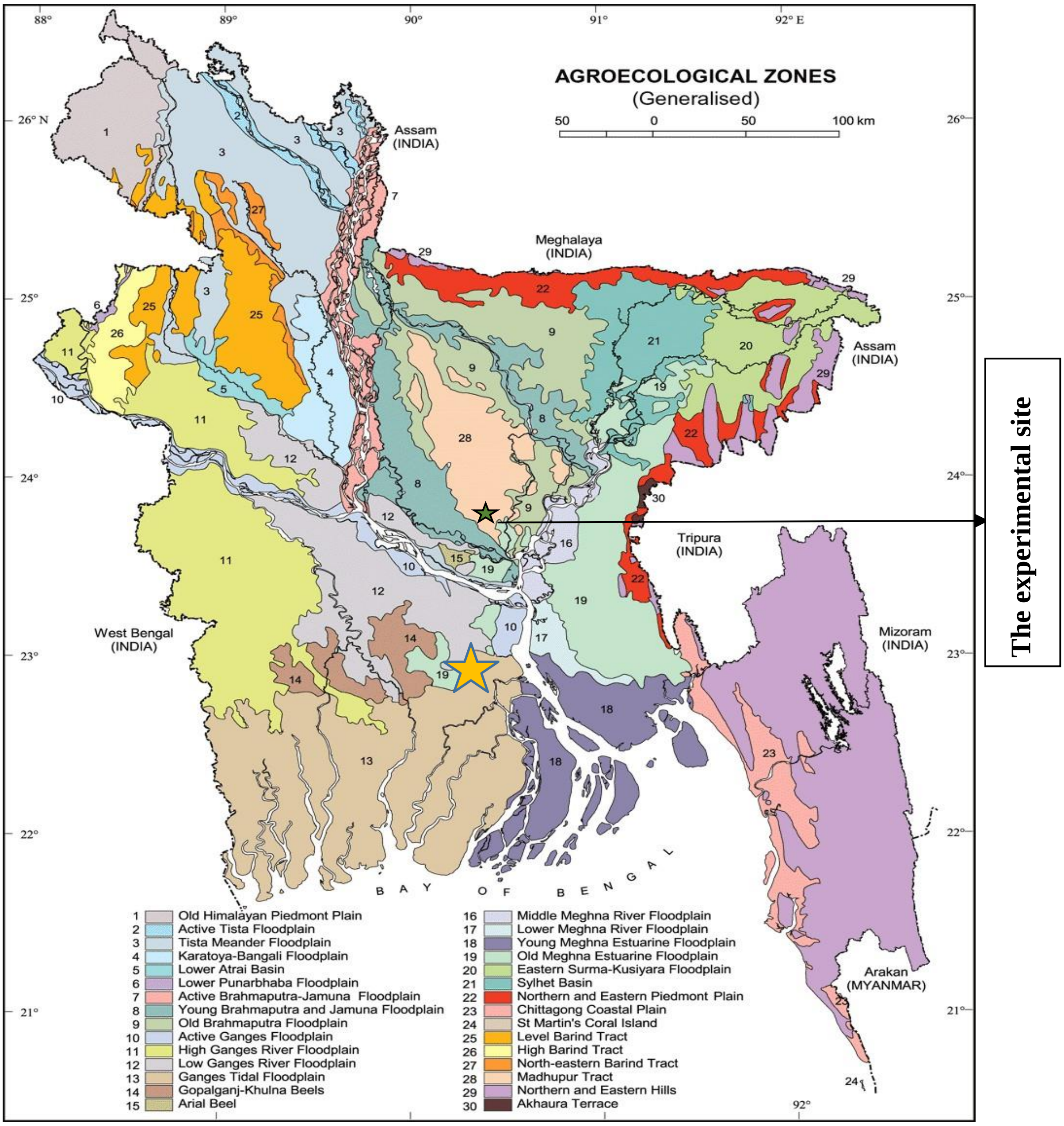
Yordanova, R. Y. and Popova, L. P. (2007). Flooding-induced changes in photosynthesis and oxidative status in maize plants. *Acta. Physiol. Pl.* **29**: 535–541.

Zhang, X. C., Zhou, G. F., Shabala, S., Koutoulis, A., Shabala, L., Johnson, P., Li, C. D. and Zhou, M. X. (2016). Identification of aerenchyma formation related QTL in barley that can be effective in breeding for waterlogging tolerance. *Theor. Appl. Genet*. **129**: 1167–1177.

Zhou, W. and Lin, X. (1995). Effects of waterlogging at different growth stages on physiological characteristics and seed yield of winter rape (*Brassica napus* L.) *Field Crops Res.* **44**: 103–110.

APPENDICES

Appendix I: Map showing the experimental site



Appendix II: Characteristics of the Experimental Field

Subject	Characteristics
Location	SAU farm, Dhaka
Agro-ecological zone	Madhupur Tract (AEZ-28)
General Soil Type	Deep Red Brown Terrace Soil
Parent material	Madhupur Clay
Topography	Fairly level
Drainage	Well drained
Flood level	Above flood level

(FAO and UNDP, 1988)

Appendix III: Initial Physical and Chemical Characteristics of the Soil

Characteristics		Value
Mechanical fraction:	% Sand (2.0-0.02 mm)	22.26
	% Silt (0.02-0.002 mm)	56.72
	% Clay (<0.002 mm)	20.75
Textural Class		Silt Loam
pH (1:2.5 Soil-water)		5.9
Organic Matter (%)		1.09
Total N (%)		0.06
Available K (ppm)		15.63
Available P (ppm)		10.99
Available S (ppm)		6.07

Appendix IV: Monthly average, maximum and minimum air temperature (^{0}C), relative humidity (%) and rainfall (mm) of the experimental site, Dhaka during the growing time (April, 2022 to July 2022)

Month	Air temperatures (ºC)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
April	33.4	24.2	67	78
May	34.7	25.9	70	185
June	32.4	25.5	81	228
July	34.1	24.3	82	232

Source: Bangladesh Meteorological Department (Climate and weather division), Agargoan, Dhaka-1212

Appendix V. Factorial ANOVA for plant height at 15 DAS

Source of variances	DF	SS	MS	F	P
Factor A	1	49.975	49.975	547.7117	0.0000
Factor B	4	38.942	9.736	106.6997	0.0000
A*B	4	3.899	0.975	10.6823	0.0000
Error	30	2.737	0.091		

Appendix VI. Factorial ANOVA for plant height at 30 DAS

Source of variances	DF	SS	MS	F	P
Factor A	1	47.808	47.808	465.6795	0.0000
Factor B	4	32.194	8.049	78.3987	0.0000
A*B	4	0.084	0.021	0.2047	
Error	30	3.080	0.103		

Appendix VII. Factorial ANOVA for plant height at 45 DAS

Source of variances	DF	SS	MS	F	P
Factor A	1	323.477	323.477	99.9219	0.0000
Factor B	4	188.867	47.217	13.2716	0.0000
A*B	4	54.142	13.536	3.8045	0.0128
Error	30	106.732	3.558		

Appendix VII. Factorial ANOVA for plant height at 60 DAS

Source of variances	DF	SS	MS	F	P
Factor A	1	321.206	321.206	90.2903	0.0000
Factor B	4	190.078	47.520	13.3577	0.0000
A*B	4	53.941	13.485	3.7907	0.0131
Error	30	106.724	3.557		

Appendix VIII. Factorial ANOVA for plant height at harvest

Source of variances	DF	SS	MS	F	P
Factor A	1	75.158	75.158	986.0609	0.0000
Factor B	4	48.524	12.131	159.1552	0.0000
A*B	4	2.930	0.732	9.6089	0.0000
Error	30	2.287	0.076		

Appendix IX. Factorial ANOVA for branch no. plant^{-1} at 15 DAS

Source of variances	DF	SS	MS	F	P
Factor A	1	3.813	3.813	8.7579	0.0060
Factor B	4	4.051	1.013	2.3260	0.0791
A*B	4	0.177	0.044	0.1019	
Error	30	13.062	0.435		

Appendix X. Factorial ANOVA for branch no. plant^{-1} at 30 DAS

Source of variances	DF	SS	MS	F	P
Factor A	1	22.816	22.816	29.3844	0.0000
Factor B	4	40.519	10.130	13.0458	0.0000
A*B	4	0.778	0.194	0.2504	
Error	30	23.294	0.776		

Appendix XI. Factorial ANOVA for branch no. plant^{-1} at 45 DAS

Source of variances	DF	SS	MS	F	P
Factor A	1	22.816	22.816	29.3844	0.0000
Factor B	4	40.519	10.130	13.0458	0.0000
A*B	4	0.778	0.194	0.2504	
Error	30	23.294	0.776		

Appendix XII. Factorial ANOVA for branch no. plant^{-1} at 60 DAS

Source of variances	DF	SS	MS	F	P
Factor A	1	37.889	37.889	48.7959	0.0000
Factor B	4	47.777	11.944	15.3829	0.0000
A*B	4	0.939	0.235	0.3025	
Error	30	23.294	0.776		

Appendix XIII. Factorial ANOVA for branch no. plant^{-1} at harvest

Source of variances	DF	SS	MS	F	P
Factor A	1	1.777	1.777	0.0299	
Factor B	4	402.602	100.650	1.6961	0.1769
A*B	4	210.604	52.651	0.8873	
Error	30	1780.242	59.341		

Appendix XIV. Factorial ANOVA for days to 1st flowering

Source of variances	DF	SS	MS	F	P
Factor A	1	102.400	102.400	409.6000	0.0000
Factor B	4	70.100	17.525	70.1000	0.0000
A*B	4	1.100	0.275	1.10000	0.3746
Error	30	7.500	0.250		

Appendix XV. Factorial ANOVA for days to 1st maturity

Source of variances	DF	SS	MS	F	P
Factor A	1	275.625	275.625	945.0000	0.0000
Factor B	4	138.400	34.600	118.6286	0.0000
A*B	4	1.000	0.250	0.8571	
Error	30	8.750	0.292		

Appendix XVI. Factorial ANOVA for above ground dry weight plant^{-1}

Source of variances	DF	SS	MS	F	P
Factor A	1	25.579	25.579	3.7468	0.0624
Factor B	4	27.354	6.839	1.0017	0.4221
A*B	4	2.384	0.596	0.0873	
Error	30	240.808	6.827		

Appendix XVII. Factorial ANOVA for pod number plant^{-1}

Source of variances	DF	SS	MS	F	P
Factor A	1	191.932	191.932	259.9718	0.0000
Factor B	4	133.270	33.317	45.1285	0.0000
A*B	4	57.333	14.333	19.4145	0.0000
Error	30	22.148	0.738		

Appendix XVIII. Factorial ANOVA for pod length

Source of variances	DF	SS	MS	F	P
Factor A	1	10.201	10.201	28.8027	0.0000
Factor B	4	10.891	2.723	7.6878	0.0002
A*B	4	0.546	0.136	0.3853	
Error	30	10.625	0.354		

Appendix XIX. Factorial ANOVA for SPAD value

Source of variances	DF	SS	MS	F	P
Factor A	1	967.567	967.567	369.9064	0.0000
Factor B	4	1793.211	448.303	171.3886	0.0000
A*B	4	21.476	5.369	2.0526	0.1121
Error	30	78.471	2.616		

Appendix XX. Factorial ANOVA for RWC

Source of variances	DF	SS	MS	F	P
Factor A	1	390.125	390.125	1.6156	0.2135
Factor B	4	3155.351	788.838	3.2669	0.0245
A*B	4	1592.914	398.228	1.6492	0.1879
Error	30	7244.009	241.467		

Appendix XXI. Factorial ANOVA for 1000 grains weight

Source of variances	DF	SS	MS	F	P
Factor A	1	509.939	509.939	95.7759	0.0000
Factor B	4	1152.269	288.067	54.1043	0.0000
A*B	4	126.602	31.651	5.9446	0.0012
Error	30	159.729	5.324		

Appendix XXII. Factorial ANOVA for yield per plant

Source of variances	DF	SS	MS	F	P
Factor A	1	100.568	100.568	138.0584	0.0000
Factor B	4	222.164	55.541	76.2459	0.0000
A*B	4	15.647	3.912	5.3699	0.0022
Error	30	21.853	0.728		

LIST OF PLATES

Plate 1: Pictorial view of the experimental site

Plate 3: Data collection from the experimental pot