SHORT TERM WATERLOGGING EFFECT ON MUNGBEAN

OAHIDA JANNAT

DEPARTMENT OF AGROFORESTRY AND ENVIRONMENTAL SCIENCE
SHER-E-BANGLA AGRICULTURAL UNIVERSITY
DHAKA-1207

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BY

OAHIDA JANNAT

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APPROVED BY:

Dr. Nazmun Naher	**Dr. A.K.M. Mahbubul Alam**
Professor	**Principal Scientific Officer**
Supervisor	**Co-Supervisor**

Dr. Jubayer-Al-Mahmud
Chairman
Examination Committee

Sher-e-Bangla Agricultural University
Sher-e-Bangla Nagar, Dhaka-1207

PABX: +88029144270-9
Fax: +88029112649
Web site:
www.sau.edu.bd

CERTIFICATE

This is to certify that the thesis entitle, **"SHORT TERM WATERLOGGING EFFECT ON MUNGBEAN"** *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 IN AGROFORESTRY AND ENVIRONMENTAL SCIENCE****, embodies the result of a piece of bonafide research work carried out by* ***Oahida Jannat*** *Registration No.*13-05664 *under my supervision and my guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Dated: June, 2020
Dhaka, Bangladesh

Dr. Nazmun Naher
Professor
Supervisor

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SHORT TERM WATERLOGGING EFFECTS ON MUNGBEAN

ABSTRACT

Waterlogging stress is one of the most atrocious environmental factors restricting the productivity of Mungbean in tropical and subtropical region. So a pot experiment was conducted at Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka, during April, 2019 to July, 2019 to evaluate the growth and yield attributes in waterlogging condition. The experiment comprised of four Mungbean varieties, Green Diamond (V_1), Crystal (V_2), Satin (V_3), and Celera (V_4) and two treatments namely control and waterlogging were designated respectively as T_1 and T_2. The experiment was laid out in two factors factorial experiment with Randomized Complete Block Design (RCBD) and three replications. Pots were placed in the water chamber after 24 days of germination for 72 hours. The results showed that both the varieties and waterlogging treatment had significant influence on growth (vegetative) and yield traits of mungbean plant. It was found that Celera showed the highest (37.040 cm) plant height in both control and waterlogging condition (31.067 cm). Among the four varieties Crystal produced the highest SPAD value (50.076 unit) than other varieties. After waterlogging treatment new leaves initiated in variety named Green Diamond (V_1) in 39 DAS followed by Celera (40 DAS). No. of leaves was higher (11) in Green Diamond in control and it became 4.666 in waterlogging treatment. Celera produced higher pod per plant both in control (20) and waterlogging (12.33). The highest yield per plant containing variety was Celera both in control (5.3083 g) and (4.1916 g) in waterlogging. So, Celera can be considered as a waterlogging stress tolerant variety for low laying or flood prone areas of Bangladesh.

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SOME COMMONLY USED ABBREVIATIONS

FULL WORD	ABBREVIATION
Agriculture	Agric.
Agro Ecological Zone	AEZ
Analysis of variance	ANOVA
And others	*et al.*
At the rate	@
Bangladesh Bureau of Statistics	BBS
Centimeter	Cm
Days After Sowing	DAS
Degree Celsius	^{0}C
Degrees of freedom	df
Etcetera	etc.
Food and Agriculture Organization	FAO
Gram	g
Kilogram	Kg
Least Significant Difference	LSD
Mean sum of square	MS
Meter	M
Ministry of Agriculture	MoA
Muriate of Potash	MOP
Oven Dry Weight	ODW
Sun Dry Weight	SDW
Total Dry Weight	TDW
Triple Super Phosphate	TSP
Percent	%
Percentage of coefficient of variation	CV%
Soil Plant Analysis Development	SPAD

CHAPTER I

INTRODUCTION

Bangladesh is a low lying country and the largest delta in the world. It is situated between the Himalayas and the Indian Ocean with a vast river basin made up of the Ganges, the Brahamaputra, the Meghna and their tributaries. Sudden flooding is a common disaster in our country due to its geographical position. Around 6.77 lakh hectares of croplands have been damaged by the recent flood that affected about 61 lakh people in 28 districts. Crops on 5.32 lakh hectares were destroyed and the rest damaged (BBS, 2019). In this phenomenon waterlogging tolerant crop varieties which are nitrogen producing are a blessing for our country.

In tropical and subtropical region, heavy rainfall in the rainy season frequently induces short time flooding in the crop field. Soil flooding occurs over vast regions throughout the world adversely affecting approximately 10% of the global land area (FAO, 2002). Soil flooding has long been identified as a major abiotic stress and the constraints it imposes on roots have marked effects on plant growth and development (Parent *et al.*, 2008). Pounding of water due to rainfall, particularly in clay soil hampers root respiration. The problem is wide spread under flash flood due to climate change. A complete crop failure due to flooding is not uncommon. The effect of flooding on plant is obviously a reduced exchange of gasses between the plants and the environment (Maberly and Spense, 1989). Oxygen deficiency is the main constraint for plants have to deal with in a flooded situation (Crawford and Brandle, 1996). Flooding-induced stress may affects directly on the guard cell causing stomatal closure and reduces photosynthetic capacity of plants (Bradford and Hsiao, 1982).

Mungbean [*Vigna radiata* (L.) Wilczek] is one of the important pulse crops of the world and is also known as greengram. Mungbean is a pulse crop under leguminous species, grown principally for its protein rich edible seeds. The species is a C_3 plant originated in the Indo-Burma region of Asia. It is a short duration grain legume having wider adaptability and low input requirements. Mungbean is a popular and important pulse crop in Asia because of its high content of easily digestible protein and wide adaptability for cultivation. Besides its utilization as food in many forms, haulms are

used as fodder and green manure. Mungbean is a prehistoric crop and grown throughout Asia, Australia, West Indies, South and North America, and Tropical and Subtropical Africa. It has the unique ability to fix the atmospheric nitrogen (58-109 kg ha^{-1}) in symbiotic association with Rhizobium bacteria, which not only enables it to meet its own nitrogen requirement but also benefits the succeeding crops (Ali, 1992). Mungbean can be cultivated as an agroforestry crop as it provides grain for the consumption and adds nitrogen to the soil. Due to its short term growth, nitrogen fixing capability, soil reinforcement and prevention of soil erosion, it is superior to other legumes. Though, pulses have been playing a vital role in the diet, the per capita availability of pulses has declined from 60.7 g day^{-1} in 1951 to 35.5 g day^{-1} in 2007 as against the FAO/WHO's recommendation of 80 g day^{-1}. Thus based on above statistics and the per capita availability, the production potential of pulses has to be increased substantially. The importance of greengram in the economy is hardly over emphasized due to its valuable and easily digestible protein (24%) with protein efficiency ratio of 2.12, carbohydrate (62%), fat (1.3%), calcium (124 mg), phosphorus (326 mg), iron (7.3 mg) and vitamin B, digestibility of 81%, biological value of 70% and net protein utilization of about 46%. It contains amino acids lysine, methionine and cysteine. It is rich in digestible protein (approximately 25–28 %) by virtue of N_2 fixation machinery (Poehlman, 1991). It is extensively grown in tropical and subtropical Asia because of its wider range of adaptability (Poehlman, 1991). This crop is fitted well in multi-cropping systems, because of its rapid growth and early maturity, results in the increase of small landholders' income and improvement of soil fertility (Nsoukpoe-Kossi *et al.*1999).

In Bangladesh, Mungbean is traditionally cultivated in the winter months, but may be cultivated year round if there any stress tolerance variety presence. In about 54982 hectares of land and about 34,400 m tons of grains are produced. In Barisal and Patuakhali this crop is widely cultivated. There is possibility of growing Mungbean in summer season and some success has already been achieved. Recently Bangladesh Agricultural Research Institute (BARI) and Bangladesh Institute of Nuclear Agriculture (BINA) have developed some genotypes of summer Mungbean. In Bangladesh total production of Mungbean was 30,000 metric tons from an area of 108,000 acres (BBS, 2005). It contributed 6.5% percent of the total pulse production of the country. It ranks third both in acreage and production among the pulses (BBS, 2004). The yield of Mungbean is quite lower than other grain legumes. For increasing pulse production it

is urgently needed to extent cultivation of pulse crops rapidly to all possible areas of Bangladesh. But the cultivation of pulse crop in that area is not easy because of the lack of flood tolerant varieties of this crop. It is needed to develop stress tolerant high yielding varieties of Mungbean by combining together the tolerant character that may have been distributed sporadically in different related genotypes. To develop waterlogging tolerant varieties of Mungbean, different genotypes and mutants have to be assessed. After proper physiological and biochemical examination, the genotypes which show flood tolerance should be identified for their adaptation to sustainable agriculture or future breeding application. With this consideration the present study was conducted to assess the growth and yield attributes of Mungbean genotypes under imposed waterlogging conditions. 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 flooding, particularly during the early stages of growth (Singh and Singh 2011). Flooding or waterlogging reduces oxygen concentrations around the roots of the submerged plants and restricts nodule activity and nitrogen fixation. Thus, Mungbean is not suited to the wet tropics, where the annual precipitation is above 1,000 mm (Fernandez and Shanmugasundaram, 1988). Although, there have been a good number of reports on the excess moisture tolerance of other upland crops such as tomato (Kuo and Chen,1980), maize (Singh and Ghildyal,1980), wheat (Musgrave and Ding,1998) etc., and soil flooding in Mungbean is not uncommon, but despite this fact, very little information is available on the physiological responses of Mungbean to soil waterlogging.

Therefore, considering the mentioned facts the present study was carried out to fulfill the following objectives:

1) To analyze the morphological and physiological changes of Mungbean due to waterlogging condition
2) To determine the yield of Mungbean in waterlogging condition

CHAPTER II

REVIEW OF LITERATURE

Now-a-days the world agriculture is counteracting multiple challenges at the same time 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), 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 necessitate to enhance the productivity of the agronomical valuable food grain legumes to meet the nutritious food demand of the geometrically increasing population by exploiting scarce natural resources more efficiently. Considering the studies, the review of literature is presented under the following heads:

2.1 Mungbean

Mungbean is an important short duration (65-90 days) legume crop of high nutritive values and nitrogen fixing ability. It is a self-pollinated diploid crop with 2n = 2x = 22 chromosomes and a genome size of 579 Mb. It is the third most important pulse crop in India, occupying nearly 3.72 million ha area with 1.56 million tons production (Ali and Gupta, 2012). Although wild, weedy and cultivated germplasm or populations of mungbean are available, very little is known regarding diversity, population structure, and gene flow and/or introgression. In addition, taxonomy of mungbean at variety or subspecies level is still arguable, and in some cases, this species is mischaracterized as other related *Vigna* species (Tomooka *et al.*, 2006).

Protein malnutrition remains a major nutrition problem in Asia and affects children most severely (WHO, 2000; UNSCN, 2010). About 150 million children worldwide are underweight and 182 million are stunted. At least 70% of these children are in Asia. Meat is a good protein source, but is either excluded from vegetarian diets or unaffordable for poor households where protein and micronutrient deficiencies are most

prevalent. However, mungbean is a cheap source of protein, and an important nutritious dietary component of vegetarians in Asian countries especially in South-east Asia (Keatinge *et al.*, 2011).

Future progress in mungbean breeding requires urgent action to identify accessions with favorable agronomic traits and to provide tools to exploit the allelic diversity of mungbean for crop improvement. Worldwide, a total of 43,027 mungbean accessions are held ex situ. Institutes with major collections are: (1) The Institute of Plant Breeding, University of the Philippines, Los Baños, Philippines (6889 accessions); AVRDC – The World Vegetable Center, Taiwan (6358 accessions (AVGRIS, 2012); the University of Georgia, Griffin, USDA-ARS, USA (3900 accessions); the National Bureau of Plant Genetic Resources (NBPGR), New Delhi, India (3147 accessions); the Regional Station Jodhpur of NBPGR in Rajasthan, India (2466 accessions); the Field Crops Research Institute of the Department of Agriculture, Bangkhen, Thailand (2250 accessions); and the National Institute of Agrobiological Sciences, Tsukuba-shi, Japan (1579 accessions) (WIEWS,2012).

2.2 Effects of waterlogging in mungbean genotypes

According to Ahmed *et al.* (2000), the effects of short term waterlogging on Mungbean and recovery from the damage were studied in a plastic greenhouse. Pot grown plants of two Mungbean cultivars, KPS1 and CNX49 were waterlogged for eight days, at the vegetative and reproductive growth stages. Photosynthetic rate (P), transpiration rate (TR), diffusive resistance (rs) and leaf water potential (ψt) were measured at the 1^{st}, 4^{th} and 8^{th} day of the 8 days waterlogging treatment and at the 4^{th} and 8^{th} day after the end of waterlogging. All these physiological parameters of both cultivars recovered to almost normal value within 4 days after the end of waterlogging at the reproductive stage and within 8 days at the vegetative stage. Waterlogging did not affect water potential, indicating that the decrease in P and TR was not associated with leaf dehydration and after the waterlogging in both KPS1 and CNXP49. Final seed yield in KPS1 and CNX49 was reduced by 16 and 19 %, respectively, by the waterlogging at the vegetative stage and by 23 and 30%, respectively, by that at the reproductive stage.

In another experiment according to Amin *et al.* (2016) a field experiment was carried out 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.

Similar experiment held by Wongipichet (2000), the results showed that, waterlogging at growth stages affected plant height, leaf dry weight/plant, stem dry weight/plant and root dry weight/plant compared to control plants. Waterlogging at growth stages also reduced the number of pods/plant and pod dry weight/plant. Moreover, Mungbean during the reproductive phase responded to waterlogging, in terms of faster leaf wilting, than that during the vegetative phase. At growth stage waterlogging throughout, waterlogging alternated with dryness and waterlogging at the beginning reduced leaf dry weight/plant, stem dry weight/plant, other parts dry weight/plant, seed dry weight/plant and plant height significantly according to the degree of waterlogging. Waterlogging also reduced harvest index, but increased root:shoot ratio.

After conducting an experiment Musgrave (2013) reported that, Mungbeans (*Phaseolus aureus* 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.

2.3 Effect of waterlogging on mungbean and other crops

Yohe and Poehlman (1972) evaluated 321 strains of Mungbean collected from different countries for yield, days to maturity for first ripe pod, plant height, length of first branches, pods per plant, seed number per pod, 100-seed weight, protein content in seed and amino acid lysine and methionine percentage and resistance to viruses and *Erysiphe polygame*. A wide range of genetic variability was found for each character examined. A comparison was made between the performance of the 32 (10%) highest yielding strains and that of the total population of 321 strains.

Chaudhary (1986) reported that nonadditive gene action controlled height, pods per plant and seed yield per plant in Mungbean. Thimmappa (1987) reported that additive gene action was pre dominant for branches per plant and 100-seed weight in Mungbean. Gupta et al. (1978) reported that 100-seed weight, plant height and days to maturity were influenced by additive gene action. Paramasivam and Rajasekaran (1980) evaluated 40 varieties of green gram. A wide range of variation was noticed in all the characters under study, especially, plant height and number of pods. Studies on gene action in Mungbean were also made by Gawonde and Patil (2005), Hegde *et al.* (1996). Krishnaswami and Rathinam (1982) evaluated Pusa Baisakhi and selection 122 for seed yield, height and four yield components. Value of the genetic coefficient of variation and genetic advance were enhanced. In general, heritability of all traits except height was increased as compared with control.

Singh *et al*. (1990) obtained information on heritability, variation and genetic advance derived from data on six yield components recorded for 18 genotypes during 1988-89. Information in genetic variability and heritability was published by Reddy *et al.* (1991), Gayen *et al.* (1991), Pundir *et al.* (1992), Holkar and Raut (1 993) in mung bean genotypes. Islam *et al.* (1999) obtained high estimates of heritability and genetic advance for plant height, number of pods per plant, seeds per pod, 100-seed weight and yield per plant.

Venkateswarlu (2001) reported high heritability and expected genetic advance along with high GCV which indicated predominance of additive gene effects for seed yield. Loganathan *et al*. (2001) made experiments with 50 gentoypes of greengram to estimate genetic variability for 10 quantative characters during rabi. High phenotypic coefficient of variability indicated the favorable effects of environment for number of clusters per plant and seed yield per plant. High genotypic coefficient of variability suggested the substantial effects of genotype for number of pods per plant and seed yield per plant. Due to high genetic advance and additive gene action, phenotypic selection were considered effective for number of pods per plant, seed yield per plant and number of seeds per pod. Nonadditive gene action was low for days to first flowering, plant height, number of branches per plant, number of pods per plant and 100-seed weight. They suggested that recurrent selection may be useful for improvement of yield.

Chakraborty and Borah (2001) studied genetic variability, heritability and genetic advance for 5 root characters viz. root length, root nodules plant, number of secondary roots per plant, root dry weight and root/shoot ratio and seed yield. Relatively, large differences between phenotypic and genotypic coefficient of variability were observed for root length, root nodules per plant and root-shoot ratio indicating that the environment greatly influences these characters. Moderately high heritability with high genetic advance for seed yield per plant, nodules per plant and root dry weight suggested the partial additive gene effects in their inheritance. However, low genetic advance for root length, nodules per plant and root shoot-ratio indicated that these traits were predominantly governed by nonadditive gene effects.

Khaimar *et al.* (2003) reported highest genotypic and phenotypic coefficients of variation for pods per plant, followed by 100-grain weight. Reddy *et al.* (2003) observed high magnitude of variability for pods per plant and grain yield per plant, while

moderate variability was recorded for pods per cluster, clusters for plant, plant height and days to 50% flowering. High heritability coupled with high genetic advance was recorded for the pods per plant, grain yield per plant, pods per cluster, clusters per plant, plant height and days to 50% flowering. High heritability and moderate genetic advance were noted for seeds per pod, 100-seed weight and days to maturity which suggested that these traits were controlled by additive gene action.

Gayen *et al.* (2004) showed moderate to high genetic coefficient of variation (GCV), heritability and genetic grain and low difference between GCV and PCV at all growth stages. Lavanya *et al*. (2005) studied variability and genetic parameters in 20 Mungbean genotypes. Results revealed significant differences for seven yield and yield attributing traits viz. number of primary branches, pod length, plant height, pods per plant, seeds per pod, 100-seed weight and seed yield per pod. Pods per plant and seed yield per plant exhibited high phenotypic coefficient of variation that indicated the favorable effect of environment on these characters. High genotypic coefficient of variation suggested the presence of substantial amount of genetic variability for 100-seed weight, seed yield per plant and pod length along with high heritability and high genetic advance as percentage of mean.

One of the first plant responses to waterlogging is the reduction in stomata conductance (Folzer *et al*., 2006). Plants exposed to flooding stress exhibit increased stomata resistance as well as, limited water uptake leading to internal water deficit (Parent *et al*., 2008). In addition, low levels of O2 may decrease hydraulic conductivity due to hampered root permeability (Else *et al.*, 2001). Oxygen deficiency generally leads to the substantial decline in net photosynthetic rate (Ashraf *et al*., 2011).This decrease in transpiration and photosynthesis is attributed to stomata closure (Ashraf and Arfan, 2005). However, other factors such as reduced chlorophyll contents, leaf senescence and reduced leaf area are also held responsible for decreased rates of photosynthesis (Malik *et al.*, 2001).

In this context, Yordanova *et al.* (2005) reported fast stomata closure in barley plants when subjected to flooding conditions. Similarly, when pea plants were subjected to flooding conditions, a prompt closure of stomata was recorded (Zang and Zang, 1994). This stomata closure of pea plants was attributed to the abscisic

acid (ABA) transport from older to younger leaves or denovo synthesis of this hormone. Furthermore, prolonged *exposure* of plants to flooding conditions could result in root injuries which in turn restrict photosynthetic capacity byinducing certain alterations in biochemical reactions of photosynthesis. These biochemical alterations include restricted activity of ribulose bisphosphate carboxylase (RuBPC), phosphoglycollate and glycollate oxidase (Yordanova and Popova, 2001), demolition of chloroplast membrane inhibiting photosynthetic electron transport and efficiency of photosystem II (Titarenko, 2000). It is evident from the literature that flooding causes a marked reduction in photosynthetic capacity of a number of plants, for example, Lolium perenne (McFarlane *et al.*, 2003), *Lycopersicon esculentum* (Bradford, 1983; Jackson, 1990) *Pisum sativum* (Jackson and Kowalewska, 1983, Zhang and Davies, 1987), and *Triticum aestivum* (Trought and Drew, 1980).

According to Li *et al.*, (2004), plants exhibit certain adaptation under waterlogging stress to maintain photosynthetic capacity Moreover, flood-induced destruction of chlorophyll has been investigated widely by a number of researchers (Jackson *et al*., 1991; Huang *et al*., 1994; Ashraf *et al*., 2011). This decrease in chlorophyll directly or indirectly affects the photosynthetic capacity of plants under waterlogged conditions (Ashraf *et al.*, 2011). The adverse effects of waterlogging on different gas exchange attributes of plants have been reported in some earlier studies.

Ashraf and Arfan (2005) reported decrease in photosynthetic rate, water use efficiency and intrinsic water use efficiency of 32-day okra plants when subjected to waterlogged conditions. It is a general consensus that stomata regulation controls the CO2 exchange rate of plants under waterlogged conditions (Ashraf and Arfan, 2005; Ashraf *et al*., 2011). Furthermore, water potential of plants is also controlled to some extent by stomata regulations (Liao and Lin, 1996). However, there are contrasting reports on the involvement of stomatal regulation in maintenance of water potential. For example, waterlogging caused a marked reduction in stomata conductance of bitter melon. This reduction in gas resulted in increased leaf water potential (Liao and Lin, 1994).

In contrast, Ashraf and Arfan (2005) found significant correlation between stomata conductance and water potential of okra plants under waterlogged conditions. In fact, these authors were of the view that osmotic potential and pressure potential are the main

factors that determine water potential. Waterlogging stress is also known to cause marked perturbation in different chlorophyll fluorescence attributes of plants. Since chlorophyll fluorescence is an excellent physiological marker that determine the primary processes involved in photosynthesis such as energy transfer due to excitation, absorption of light and photochemical reactions occurring in the PSII (photosystem II) (Deell *et al*., 1999; Saleem *et al*., 2011). Therefore, changes in chlorophyll fluorescence parameters determine the function and stability of photosystem II. The plants subjected to waterlogged conditions exhibit certain alterations in this physiological marker. For example, when Cork oak (*Quercus variabilis*) and China wingnut (*Pterocarya stenoptera*) were subjected to waterlogging stress, a prominent decrease in maximum quantum efficiency (Fv/Fm) was recorded (Hua *et al.,* 2006). Likewise, decrease in the maximum quantum yield of PS II photochemistry (Fv/Fm) was also recorded in flied beans when subjected to varying days of waterlogging stress (Pociecha *et al*., 2008). PSII photochemistry was also impaired due to waterlogging in *Medicago sativa.* The decrease in Fv/Fm indicated the sensitivity of photosynthetic apparatus to abiotic stress and also inability of the plants to regenerate rubisco under stressful conditions (Smethurst *et al*., 2005).

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. For acclimation in waterlogging environment, avoidance of water loss through reduction in leaf area and the induction of adventitious roots proliferation have been reported in soybean by Bacanamwo and Purcell (1999). In their study, waterlogging resulted in increased adventitious root proliferation in tolerant genotypes. This in turn indicated significance of adventitious roots proliferation as an important trait. It provides an early and fast root growth recovery. Similarly, low degree of root decay and formation of adventitious roots along with aerenchyma has been reported as important characteristics to confer tolerance under waterlogging in cowpea (Takele and McDavid 1994) and faba bean (Solaiman *et al*., 2007). Similar to this experimental observations, inhibition of growth has been reported in sensitive genotypes in field bean (Pociecha *et al*., 2008), tomato (Else *et al*., 2009) and common bean (Celik and Turhan 2011).

The formation of new roots at the upper most part of the tap root (transition zone between root and shoot) might have occurred as a consequence of the death of existing root tips (Palta 2007). These newly formed roots under waterlogging represent not only the losses of previously-invested carbon, but an investment of new carbon (Palta *et al*., 2010). The malfunctioning of root systems under anoxia and enhanced production of adventitious roots was also reported earlier in several plant species like maize (Wenkert *et al*., 1981), *Rumex* spp. (Visser *et al*., 1996) and Mungbean (Islam *et al*., 2010). Visser *et al*., (1996) reported that accumulation of ethylene has a role in the formation of flooding-induced adventitious roots formation. The production of new thick roots reflects the death and decay of existing roots (Malik *et al*., 2001). Formation of adventitious roots is viewed as an indicator of the presence of adaptive mechanism in plants tolerant to excess soil water (Jackson and Drew 1984). This trait allows the root system to obtain oxygen directly from the air because the adventitious roots formed in the soil and even at the soil surface. We observed reduction in number of nodules per plant in all genotypes of mung bean at 9 days of waterlogging but tolerant genotypes maintained higher number of nodules per plant. Similar observations have been reported in cowpea (Hong *et al*., 1977) and soybean (Matsunami *et al*., 2007).

Cell membrane stability has been widely used to express stress tolerance in plants and higher membrane stability is correlated with stress tolerance by Premachandra *et al*. (1992). Membrane disintegration as a result of oxygen deprivation and solute leakage upto 40 times has been reported in four days waterlogged pea plants (Jackson *et al*., 1982). In another study, waterlogging significantly reduced the relative water content (RWC) and membrane stability particularly in sensitive Mungbean genotypes. Wilting in plants under excess of water during flooding has been attributed to higher resistance to mass flow of water through the roots (Jackson and Drew 1984). Flooding-tolerant plant species develop adaptive mechanisms to maintain better water relationship by means of stomatal conductance (Malik *et al*., 2001).

Yellowing of the plants and reduction in total chlorophyll content in the leaves of Mungbean plants was observed during waterlogging. Similarly, reduction in total chlorophyll content as a result of flooding has been reported in maize (Prasad *et al*., 2004), sesame (Mensah *et al*., 2006) and onion (Yiu *et al*., 2008). Under waterlogging, yellowing of the plant might be due to reduction in leaf nitrogen (Bacanamwo and Purcell 1999), nodulation and N fixation and production of toxic

substances such as nitrites and sulphides which move from the soil through roots to the leave if carried upward in large quantities (Ezin *et al*., 2010). In addition, waterlogging results in reduced soil nitrogen through rapid volatilization and denitrification (Ali *et al.*, 2012). During waterlogging tolerant genotypes maintained relatively higher level of carotenoids and higher ratio of total carotenoids and total chlorophylls indicated the protective role of carotenoids in waterlogging tolerance.

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.

According to Pociecha (2008), Field bean plants were subjected to flooding stress for 7 days, during two stages of development: at the vegetative phase (4-week-old seedlings) and at the generative phase (8-week-old plants). A strong reduction in stem elongation and leaf area as well as in dry matter production was observed as a result of flooding. The responses from vegetative plants were greater than in generative plants. Waterlogging decreased chlorophyll a and b in leaves, notably at the vegetative stage, and persisted after cessation of flooding. After flooding, photosynthesis was strongly reduced and positively correlated with decreased stomatal conductance. The results show that an excess of water in the soil limits growth and injures the photosynthetic apparatus in field beans, but that the extent of the injury is strongly age dependent.

By Bacanamwo and Purcell (1999) for acclimation in waterlogging environment, avoidance of water loss through reduction in leaf area and the induction of adventitious roots proliferation have been reported in soybean. Waterlogging resulted in increased adventitious root proliferation in tolerant genotypes. This in turn indicated significance of adventitious roots proliferation as an important trait. It provides an early and fast root growth recovery.

Similarly, Takele and McDavid (1995) stated that low degree of root decay and formation of adventitious roots along with aerenchyma has been reported as important characteristics to confer tolerance under waterlogging in cowpea and faba bean

(Solaiman *et al*., 2007). Inhibition of growth has been reported in sensitive genotypes in field bean (Pociecha *et al*., 2008), tomato (Else *et al.,* 2009) and common bean (Celik and Turhan 2011).

According to Palta (2007), the formation of new roots at the upper most part of the tap root (transition zone between root and shoot) might have occurred as a consequence of the death of existing root tips .These newly formed roots under waterlogging represent not only the losses of previously-invested carbon, but an investment of new carbon (Palta *et al.,* 2010). The malfunctioning of root systems under anoxia and enhanced production of adventitious roots was also reported earlier in several plant species like maize (Wenkert *et al*., 1981), *Rumex* spp. (Visser *et al*., 1996) and mungbean (Islam *et al*., 2010).

Visser *et al*. (1996) reported that accumulation of ethylene has a role in the formation of flooding-induced adventitious roots formation. The production of new thick roots reflects the death and decay of existing roots (Malik *et al*., 2001). Formation of adventitious roots is viewed as an indicator of the presence of adaptive mechanism in plants tolerant to excess soil water (Jackson and Drew 1984). This trait allows the root system to obtain oxygen directly from the air because the adventitious roots formed in the soil and even at the soil surface. It was observed that reduction in number of nodules per plant in all genotypes of mung bean at 9 days of waterlogging but tolerant genotypes maintained higher number of nodules per plant. Similar observations have been reported in cowpea (Hong *et al.* 1977) and soybean (Matsunami *et al.* 2007).

By Promod kumar, a study was conducted to examine the physiological response of contrasting mung bean Plants were waterlogged at vegetative stage (30 days after sowing) for 3, 6 and 9 days. Waterlogging resulted in decreased leaf area, crop growth rate, root growth and nodules number, membrane stability index, photosynthesis rate, chlorophyll and carotenoid contents, flowering rate, pod setting, yield and altered dry matter partitioning. Sensitive genotypes showed large reductions in aforementioned physiological traits and slow recovery in photosynthesis rate. On the other hand, tolerant genotypes maintained higher photosynthetic rate, chlorophylls and carotenoids, growth rate, membrane stability and fast photosynthetic recovery under waterlogging. After 9 days of exposure to waterlogging, photosynthetic rate and yield losses in most sensitive genotype (MH-1K-24) were 83 and 85 %, respectively. On an average,

photosynthetic loss at 3, 6 and 9 days of waterlogging was 43, 51, and 63 %, respectively, while grain yield loss was 20, 34 and 52 % respectively.

Cell membrane stability has been widely used to express stress tolerance in plants and higher membrane stability is correlated with stress tolerance by Premachandra *et al*. (1992). Membrane disintegration as a result of oxygen deprivation and solute leakage upto 40 times has been reported in 4 days waterlogged pea plants (Jackson *et al*., 1982; Rawyler, *et al*., 2002). In our study, waterlogging significantly reduced the relative water content (RWC) and membrane stability particularly in sensitive Mungbean genotypes. Similar reduction in relative water content (RWC) has been reported under flooding stress in pineapple by Min and Bartholomew (2005). Wilting in plants under excess of water during flooding has been attributed to higher resistance to mass flow of water through the roots (Jackson and Drew 1984). Flooding-tolerant plant species develop adaptive mechanisms to maintain better water relationship by means of stomatal conductance (Malik *et al*., 2001).

Yellowing of the plants and reduction in total chlorophyll content in the leaves of mung bean plants was observed during waterlogging. Similarly, reduction in total chlorophyll content as a result of flooding has been reported in wheat, maize (Prasad *et al*., 2004), sesame (Mensah *et al*., 2006) and onion (Yiu *et al*., 2008). Under waterlogging, yellowing of the plant might be due to reduction in leaf nitrogen (Bacanamwo and Purcell 1999), nodulation and N fixation and production of toxic substances such as nitrites and sulphides which move from the soil through roots to the leave if carried upward in large quantities. In addition, waterlogging results in reduced soil nitrogen through rapid volatilization and denitrification (Ali *et al*., 2012). During waterlogging tolerant genotypes maintained relatively higher level of carotenoids and higher ratio of total carotenoids and total chlorophylls indicated the protective role of carotenoids in waterlogging tolerance.

Waterlogging has been reported to severely affect the process of photosynthesis in plants (Li *et al*., 2011). We observed reduction in rate of photosynthesis in mung bean genotypes under waterlogging stress. Reduction in photosynthesis within a day after waterlogging was also reported earlier in snap bean (Lakitan *et al*., 1992). Decrease in rate of photosynthesis under waterlogging has been attributed to stomatal closure (Yordanova *et al*., 2005), decrease in leaf chlorophyll concentration (Bradford 1983),

production of ethylene (Ahmed *et al*., 2006), reductions in sink demand (Robert and Robert 1984), and disruption of the translocation of photosynthates (Chen *et al*., 2005). In *Spinacia oleracea* photosynthesis decreased due to disruption of PSII and reductions in chlorophyll pigments under waterlogging (Schnettger *et al*., 1994). Damage to light-harvesting complex has also been reported in flooded tomato (Janowiak *et al*., 2002) and mung bean (Ahmed *et al*., 2006). The rate of photosynthesis under flooding may decrease due to increased photorespiration and reduced ribulose bisphosphate carboxylase (RuBisCO) activity (Yordanova and Popova 2007). Mung bean tolerant genotypes (T 44 and MH- 96-1) showed faster recovery after waterlogging termination probably due lesser damage to photosynthetic machinery was caused by waterlogging treatment. In our study, waterlogging initially enhanced or maintained normal rate of leaf respiration in mung genotypes.

Liao and Lin (2001) reported the significant enhancement in leaf respiration during flooding. This might be related to the additional energy consumption for homeostasis maintenance and adaptation of the plants under waterlogging. Maintenance respiration is known to accelerate during adaptation, which indicates additional energy consumption (Bragina *et al*., 2001). Further, leaf respiration was suppressed, which might be related to the fact that the genotype is already adapted to hypoxia. Maintenance of normal leaf respiration in mung bean genotypes T-44 throughout waterlogging, suggested its better adaptability to excess water environment. Rate of respiration in mung bean genotypes was increased after waterlogging termination probably due to the need of ATP for recovery and availability of photosynthates.

Waterlogging generally reduced the growth of plant components resulting in lesser total dry weight (TDW). Waterlogging reduced relative TDW as a result of reduced dry weight of plant components. Tolerant genotypes had more dry matter because they were lesser affected by waterlogging. The tolerant genotypes maintained greater root, shoot and leaf dry matter under waterlogging than the sensitive cultivars. Therefore, tolerant genotypes with vigorous shoot and root growth were better able to tolerate transient waterlogging (Hartley *et al*., 1993). The reduction in root dry matter is probably due to reduction in dry matter of both tap root and adventitious root as a result of a reduction in root length and branching. Earlier studies also showed the decline of both plant growth and accumulation and redistribution of dry matter by waterlogging after anthesis in wheat (Li *et al*., 2011). It was shown earlier that plants invest a large proportions of

carbon in their root system (Hooda *et al*., 1990) and the production of new roots after waterlogging, represent not only losses of a previously-invested carbon, but also an investment in new carbon (Palta *et al*., 2010).

An alternative explanation is that transpiration flow drawn through the waterlogged roots is partially replaced by that through well-aerated adventitious roots, thereby sweeping fewer phytohormones out of waterlogged roots and into the leaves. This could reduce delivery of stomatal closing factors from the oxygen-deficient root system (Else *et al.* 2006), but only if water flow rate is the driving force behind its entry into xylem sap of the waterlogged roots.

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).

2.4 Present scenario of pulse *i.e* Mungbean cultivation

Mungbean (*Vigna radiate* (L.) Wilczek) is an important diploid crop with 2n=22 chromosomes. It belongs to the genus Vigna that is composed of more than 150 species originating mainly from Africa and Asia where the Asian tropical regions have the greatest magnitude of genetic diversity (USDA-ARS GR1N, 2012).

Rahim *et al.* (2010) reported that Mungbean is an important leguminous crop mainly cultivated in tropical, subtropical and temperate zones of Asia including Bangladesh, India, Pakistan, Myanmar, Indonesia, Philippines, Sri Lanka, Nepal, China, Korea and Japan. Cultivation of the crops extends across wide range of latitudes (40^{o} N or S) in

regions with diurnal temperatures of growing seasons are > 20^{o} C (Lawn and Ahn, 1985).

Mungbean is one of the most important pulse crops in our country. The agro ecological condition of Bangladesh is quite favorable for growing the crop. The demand of grain legumes is increasing day by day in Bangladesh due to increase in consciousness of the nutrition of leguminous foods among the common people (BBS, 2012).

According to Rahman (2007) in Bangladesh total production of pulses is only 0.65 million ton against 2.7 million tons requirement. This means the shortage is almost 80% of the total requirement. According to FAO (2013) recommendation, a minimum intake of pulse by a human should be 80 gm/day, whereas it is 7.92g in Bangladesh (BBS, 2012). This is mostly due to low yield (MoA, 2013).

According to AIS (2017), at present the total land area under pulse crops are 8,85,700 hectares of land and the total production of pulses in our country is 10,05,100 metric tons that is less than the country's requirement. It is also reported that the total Mungbean cultivated area of Bangladesh is 2,05,700 ha that produced 2,25,500 tons Mungbean in 2015-16. It holds the third in protein content and 4th in both acreage and production in Bangladesh (MoA, 2013).

Ali (2014) investigated the effect of sowing time on yield and yield components of different Mungbean varieties, a field experiment was conducted during 2012 at agronomic research area, University of Agriculture, Faisalabad, Pakistan. The experiment was designed according to randomized complete block design under split plot arrangement in triplicate. Different sowing times (15th June, 25th June, 5th July and 15th July) were assigned to main plots and varieties (NM-2011, NM-2006, AZRI-2006 and NM-98) were allocated to subplots. Different Mungbean varieties also responded significantly towards yield and yield components and NM-2011 variety outperformed in terms of maximum seed yield (1282.87 kg ha-1) than rest of varieties.

Parvez *et al.* (2013) conducted at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh during the period from October to January 2011 to study the performance of Mungbean as affected by variety and level of phosphorus. The experiment comprised four varieties viz. BARI Mung-6, Binamoog-4, Binamoog-6 and Binamoog-8 and four levels of phosphorus viz. 0, 20, 40 and 60 kg P2O5 ha-1,

and laid out in a Randomized Complete Block Design with three replications. Results revealed that the longest plant, highest number of branches plant-1, number of total pods plant -1, seeds plant -1 and seed weight plant-1 were obtained from BARI Mung-6. Binamoog-6 produced the highest seed yield which was as good as Binamoog-8. The second highest and the lowest seed yield were recorded from Binamoog-4 and BARI Mung-6.The highest stover yield was obtained from Binamoog-8 followed by Binamoog-4. The lowest stover yield was recorded from BARI Mung-6.

Salah Uddin *et al.* (2009) carried out in experimental field of the department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh to investigate the interaction effect of variety and fertilizers on the growth and yield of summer Mungbean during the summer season of 2007. Five levels of fertilizer viz. control, N + P +K, bio-fertilizer, Bio-fertilizer + N + P + K and Bio fertilizer + P + K. and three varieties BARI mung 5, BARI mung 6 and BINA moog 5 were also used as experimental variables. The experiment was laid out in Randomized Block Design with fifteen treatments where each treatment was replicated three times. BARI mung-6 obtained highest number of nodule plant^{-1} and higher dry weight of nodule. It also obtained highest number of pod plant $^{-1}$, seed plant $^{-1}$, 1000 seed weight and seed yield.

Rehman *et al.* (2009) a field experiment to study the effect of five planting dates viz. 30th March, 15th April, 15th May, 15th June and 15th July on two Mungbean varieties i.e. NM-92 and M-1 were evaluated at NWFP Agricultural University, Peshawar during summer 2004. Significant differences were observed among various planting dates for all the parameters except days to 50% flowering and grains pod-1. Sowing date of 30th March took more days to emergence, flowering and physiological maturity. Maximum emergence m-2 was recorded for 15th April sowing. The crop attained maximum plant height under 15th May sowing. Highest grain yield was recorded for early planting of 30th March. Both Mungbean varieties produced statistically similar grain yield. It is concluded from the experiment that Mungbean.

2.5 Socio economic importance of Mungbean

Mungbean is an important eco-friendly short term leguminous crop of dry land agriculture. It contents minerals, proteins and also serves as a food filter, resistant starch and dietary fibers (BBS, 2010). On the nutritional point of view, Mungbean is one of the best among pulses (khan, 1981). Being protein, mineral and vitamin rich source, it

is a crucial ingredient in Bangladesh diets. It is widely used as “DAL” in the country like other pulses. Mungbean is a summer pulse crop with short duration (70-9- days) and high nutritive value. The seeds content 22-28% protein 60-65% carbohydrates, 1-1.5% fat, 3.5-4.5% fibres and 4.5-5.5% ash, it has many effective uses, green pods in cooking as peas, sprout rich in vitamins and amino acids.

Lawn (1985) said that this crop can be used for both seed and forage since it can produce a large amount of biomass and then recover study was carried out to investigate the varietal after grazing to yield abundant seeds.

Mungbeans are a high source of nutrients like manganese, potassium, foliate, vitamin B and many more. Pulse protein is rich in lysine that is deficient in rice. Its edible grain is characterized by good digestibility, flavor, high protein content and absence of any flatulence effects (Ahmed *et al.,* 2008). Because of their high nutrient density, Mungbeans can defend against several chronic, age-related diseases, cancer, diabetes and obesity. It increases immunity and fight against harmful bacteria, viruses, cold, rashes, irritations and more.

El khimsawy (1998) said that it can be used in broilers diets as a non-traditional feed. Ihsan *et al.* (2013) stated that Mungbeans contents very low levels of oligosaccharides (sugars influence flatulence), is a good protein source (23%) with high digestibility and suitable as baby food. It is mostly used as food such as porridge, flour products, beverage products, cakes, noodles, sprouts and a small portion of fodder.

CHAPTER III

MATERIALS AND METHODS

The materials and methods that were used for conducting the experiment are presented under the following headings:

3.1 Location of the experimental plot

The experiment was conducted at the research field of Agroforestry and Environmental Science department, at Sher-e-Bangla Agricutural University, Sher-e-Bangla Nagar, Dhaka, Bangladesh. A pot experiment was conducted at this site among four Mungbean germplasms. The duration of the experiment was April, 2019 to July, 2019. This site is 90.2°E and 23.5°N Latitude and at Altitude of 8.25 m from the sea level.

3.2 Climatic condition

The experimental area was under the sub-tropical monsoon climate, which was characterized by heavy rainfall during kharif season (April to September) and scanty in the Rabi season (October to March). The month of June in Dhaka experiences very rapidly increasing cloud cover, with the percentage of time that the sky is overcast or mostly cloudy increasing from 69% to 86%. The average minimum temperature (usually the minimum temperature was noted during the night) in Dhaka in April was 23.0°C (73.4°F). The amount of rainfall in April was high with an average of 78 mm (5.4 in). The average maximum temperature was around 33.0°C (91.4°F). There was little rainfall during the month of October, November, December and January.

3.3 Soil Type

Soil of experimental pots was collected from Sher-e-Bangla Agricultural university crop field which was sandy loam with some manure and cowdung. During waterlogging soil sample contents soil pH is about 5.6 and soil series-tejgaon and General soil-noncalcarious dark grey soil.

3.4 Collection of plant Materials

This experiment comprised of four Mungbean germplasms V_1 - Green Diamond, V_2 - Crystal, V_3 – Satin, V_4 – Celera which were collected from Pulse Research Center, BARI, Gazipur. The origin of these germplasms is Australia.

3.5 Treatment of the Experiment

This two factors pot experiment was laid out in the Randomized Complete Block Design (RCBD) with three replications.

Factor A: Two Treatments

(T_1 – Control, T_2 - 72 hours artificial waterlogging condition)

Factor B: Four mungbean germplasms

(Origin: Australia)

V_1 - Green Diamond

V_2 - Crystal

V_3 – Satin

V_4 – Celera

Factor B: 72 hours artificial waterlogging condition

3.6 Pot Preparation

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 MP per pot were incorporated uniformly into the soil. Clean and dried plastic pots of 10 liter size were used for each germplasm. Each pot was then filled with 8 kg previously prepared growth media (soil and cow dung mixture). Treatments were replicated three 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.

Plate 1: Pot Preparation

Preparation of artificial water chamber

A brick built water chamber was prepared for creating waterlogging condition. Water chamber was built measuring 3 meter × 1 meter in length and breadth. Chamber height was 1 meter. Pots were placed in the water chamber after 24 days of germination for 72 hours next. The water level was 3 cm high from the soil level.

Plate 2: Artificial waterlogging Chamber

3.7 Intercultural operations

i) Weeding

Weeding were accomplished as and whenever necessary to keep the seedlings free from weeds for better soil aeration and proper nutrition.

ii) Thinning

When the plants were well established, the plants were given a uniform moderate thinning. Each pot contained four Mungbean plants.

iii) Irrigation

Light irrigation was provided immediately after germination and it was continued till the seedlings establishment in the pots when needed.

iv) Insect and disease control

No remarkable disease and pest attack was observed.

3.8 Harvesting

The harvesting was not possible to be done on a particular date because fruit initiations as well as fruit maturation period in different plants were not similar probably due to use of different manures and genetic characters of germplasms. Those were harvested over a period of time. The crop under investigation was harvested for the first time on 30 May, 2019 and the last harvesting was done 8 July, 2019.

3.9 Data collection

Four plants were selected randomly from each pot for data collection in such a way that the border effect could be avoided for the highest precision. Data on the following parameters were recorded from the sample plants during the course of experiment.

3.9.1 Plant height (cm)

Plant height was measured from sample plants in centimeter from the ground level to the tip of the longest stem of four plants and mean value was calculated. Plant height

was measured with a meter scale from three plants at 22days and 75 days after transplanting of seedling.

3.9.2 Leaf length (cm)

A meter scale was used to measure the length of leaves. Leaf length of four plants was measured in centimeter (cm) at 34 days after plantation. It was measured from the base of the petiole to the tip of the leaf. Most of the leaves of each plant were measured separately and the average it. Only the smallest young leaves at the growing point of the plant were excluded from measuring.

3.9.3 Number of Leaves per Plant

The number of leaves per plant was counted by unit pot wise from four selected plants and then averaged at 34 days after planting.

3.9.4 Chlorophyll content in leaf (SPAD Unit)

Chlorophyll content of leaf was measured by SPAD meter (SPAD 502 chlorophyll meter). Data was recorded from 3 leaves of each sampling plant and at three stages *i.e* vegetative stage, flowering stage and pod filling stage.

Plate 3: Chlorophyll content measurement

Plate 4. Measuring chlorophyll content (SPAD Unit) by SPAD meter

3.9.5 No. of pods per plant

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

3.9.6 Length of pod

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

3.9.7 No of Seed per pod

Number of seed per pod was counted by unit plant in a pot wise from four plants and then averaged.

3.9.8 Moisture percentage

Moisture percentage per pot was measured by the following formula:

$$\%\ Moisture\ content = \frac{weight\ of\ fresh\ seeds - weight\ of\ dry\ seeds}{weight\ of\ fresh\ seeds} \times 100$$

3.9.9 Hundred seed weight (g)

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

3.9.10 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).

3.10 Statistical analysis

The data obtained for different parameters were statistically analyzed to observe the significant difference among the treatment. The recorded data on different parameters were statistically analyzed by using Statistic 10 software to find out the significance of variation resulting from the experimental treatments. The mean values for all the treatments were accomplished by Dancan test. The significance of difference between pair of means was tested at 5% and 1% level of probability. All recorded data were analyzed using analysis of variance (ANOVA) and means were compared using Least Significant Difference (LSD) test according to Gomez and Gomez (1984).

CHAPTER IV

RESULTS AND DISCUSSION

In this experiment, efforts were made to find out the effect of short duration waterlogging or waterlogging stress on growth and yield contributing parameters of four Mungbean germplasms. Data on different parameters were analyzed statistically and the results have been presented in this chapter. The results are furnished in the form of tables and illustrated through the figures wherever necessary under appropriate headings.

4.1 Effect of Waterlogging on growth and morphological/physiological characteristics

4.1.1 Plant height (cm)

4.1.1.1 Effect of waterlogging on plant height (cm) of Mungbean

Plant height is an important growth index of plant, which is positively correlated with yield of Mungbean in vegetative and fruiting stage. Effect of waterlogging on plant height was statistically significant at 5% significant level. The height of four germplasm was measured and higher plant height was observed in control 37.04 cm, and lower 18.48 cm with waterlogging. It was perceived that the rate of increasing plant height 'before waterlogging' is faster than 'after waterlogging'. Plant molecular responses to this stresses in particular low-oxygen stress. Together, rainfall and groundwater table depth influence soil hydrology, controlling physiological characteristics in plants to adapt to changes in water availability, such as rooting depth (Fan *et al*. 2016). A strong reduction in stem elongation was found by Pociecha *et al.* (2008) due to flooding condition.

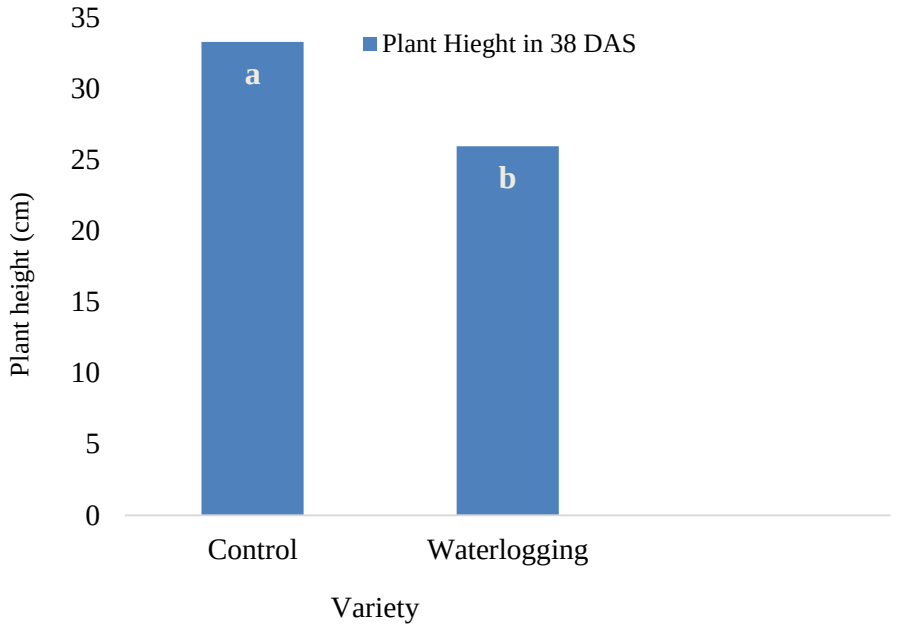

Figure 1. Effect of waterlogging on plant height (cm) of Mungbean (Here, CV% 2.87, $LSD_{(0.05)}$ - 1.0517)

4.1.1.2 Effect of germplasms on plant height (cm)

Effect of Waterlogging stress on different genotypes was statistically significant at 5% significant level (Figure 2). At vegetative stage the highest plant height was recorded in V_4 - Celera (37.04 cm) and this germplasm was measured in 31.067 cm after facing waterlogging. The lowest plant height observed in Satin (V_3) was 18.487 cm after waterlogging which was 35.077 cm in control condition. The order of germplasms according to plant height after waterlogging was Celera > Green-diamond > Crystal >Satin. Significant difference observed almost all the germplasm, the most difference observed in germplasm named satin (V_3). The germplasm named Celera was more susceptible in waterlogging condition for the plant height.

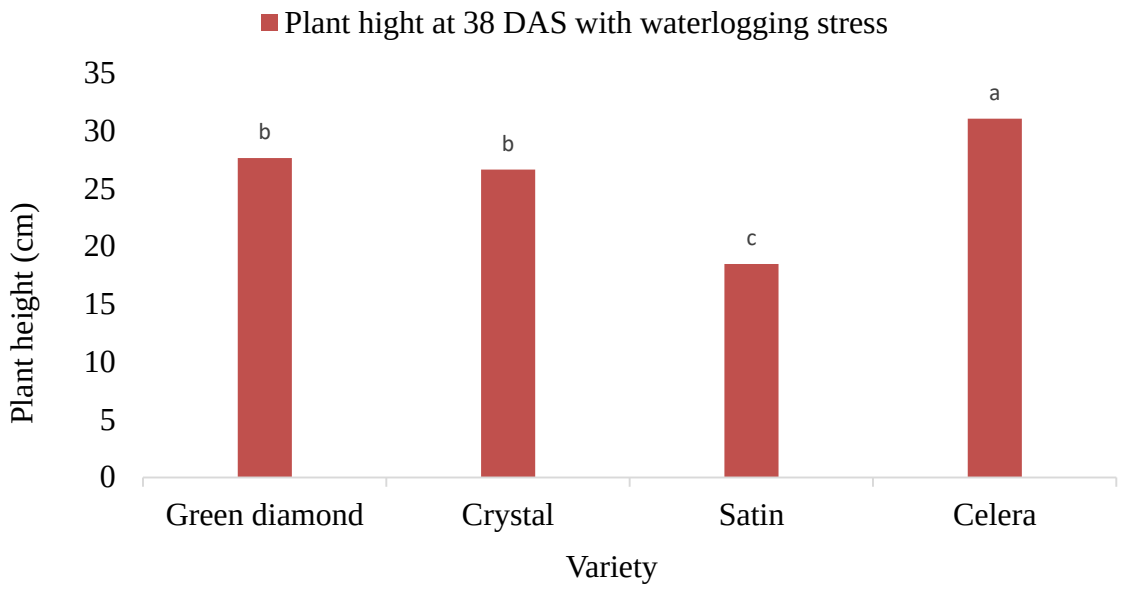

Figure 2. Varietal effect of waterlogging on plant height (cm) (Here, CV% 2.87, $LSD_{(0.05)}$ – 0.504]

4.1.1.3 Interaction effect of germplasm and waterlogging on plant height (cm)

The interaction effect on plant height between germplasm and waterlogging condition (T_2) was found significantly different. Plant height was measured in 4 Mungbean germplasms at 26 days after sowing and data are presented in the Table 1. According to plant height the series of germplasm is Celera > Satin> Green Diamond > Crystal at vegetative stage in control. Subsequently, tolerating waterlogging the highest value of plant height was in Celera (31.067 cm) which was in control condition 37.047 cm and it was in decreasing rate. Among others germplasms respectively Green Diamond, Crystal, Satin were measured in 32.667 cm, 28.477 cm, 35.077 cm in control condition after 38 DAS at flowering stage. On the other hand those germplasms respectively got the height 27.65 cm, 26.64 cm, 18.487 cm at 38 DAS after tolerating 72 hours waterlogging. After 72 hours waterlogging, the increasing vegetative growth being slow. Voesenek and Blom (1996) stated that the elongation of stems and petioles may enable plants to emerge from the water in aquatic and waterlogging tolerant terrestrial species. This variation in plant height might be recognized to the genetic characters. But if plants are reserved in the field for longer period the life span of plants are extended further 37 days giving new flowers and fruits. Similar findings of plant heights were obtained by Farghali and Hossein (1995). 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 , according to Solaiman *et al.* (2007); Pociecha *et al.* (2008); Celik and Turhan, (2011).

Table 1. Interaction effects of germplasms and treatments on plant height (cm)

Germplasm ×Treatments	**Plant height (cm) after 38 DAS with waterlogging stress**
Green Diamond × Control	32.663 c
Crystal × Control	28.477 e
Satin × Control	35.077 b
Celera × Control	37.040 a
Green Diamond × Waterlogging	27.657 f
Crystal × Waterlogging	26.647 ef
Satin × Waterlogging	18.487 g
Celera × Waterlogging	31.067 d
CV%	2.87
LSD (0.05%)	0.693

4.1.2 Number of leaves per plant

4.1.2.1 Effect of waterlogging on number of leaves

The influence of waterlogging on the number of leaves plant^{-1} was found significantly different in Figure 3. Waterlogging condition adversely affected the production of leaf number in Mungbean plants. The maximum numbers (11) of leaves were found higher at control than waterlogging condition control. The reason is that leaves are also very receptive to waterlogging stress; respiration changes in the leaf, leaf chlorophyll content, and photosynthetic assimilation have been detected during a waterlogging period (Parolin, 2000).

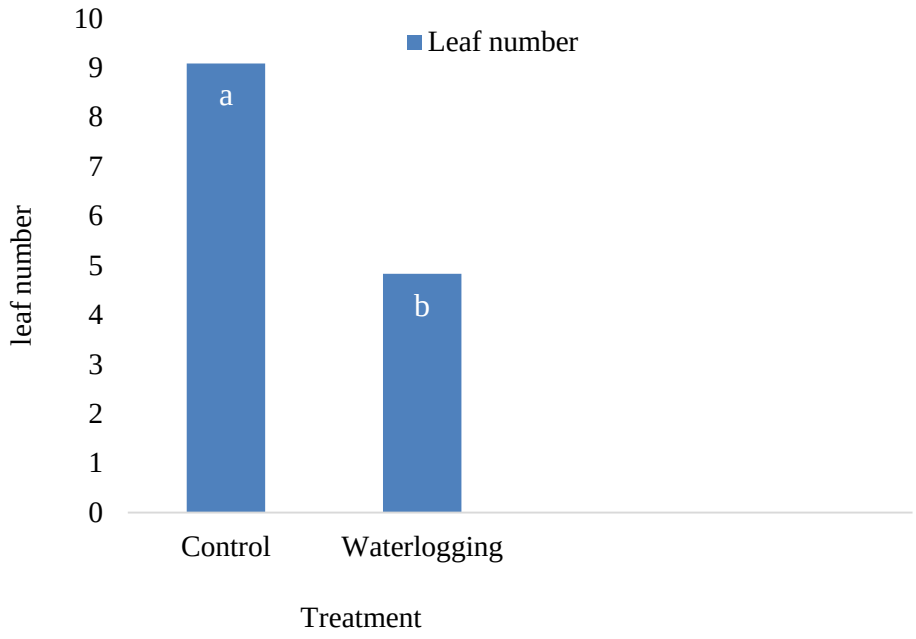

Figure 3. Effect of waterlogging on number of leaves in Mungbean

4.1.2.2 Effect of germplasms on number of leaves

The number of leaves plant^{-1} was found significantly different among germplasms in Figure 4. Through, waterlogging effect the highest number of leaves was counted in Crystal (5) and Celera (5) and lowest number counted in Green diamond (4.666) and Satin (4.666). But in control number of leaves was counted in higher number for each germplasm. Subsequently, in waterlogging Mungbean plants exuded leaves for excessive water up taken because too much water results in soft and limp leaves. The soil waterlogging genotype interaction effect on the number of leaves plant^{-1} was non-significant but small scale genotypic differences were observed. Nawata (1989) observed that short-term waterlogging did not affect the changes of the number of leaves in all the germplasms of yard long bean.

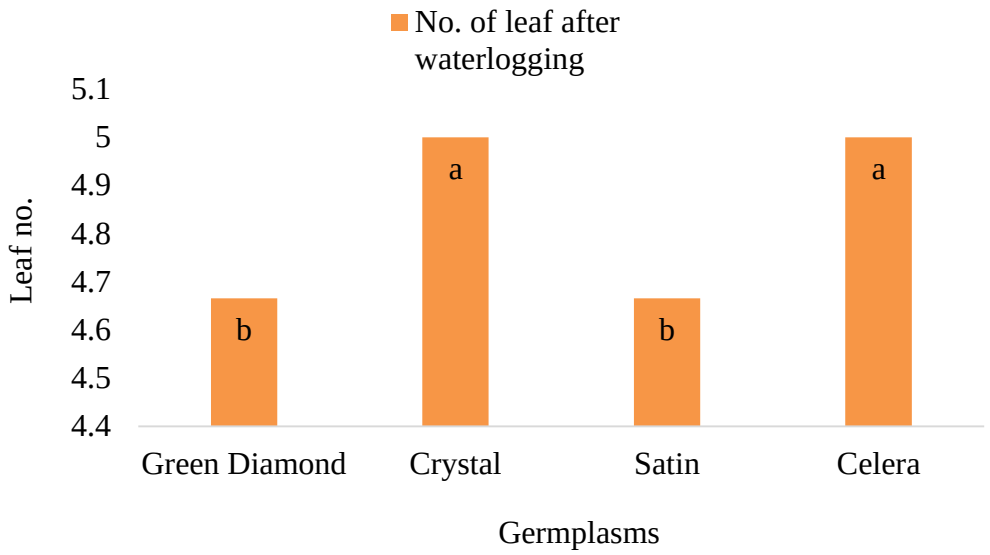

Figure 4. Effect of germplasms on number of leaves, (here CV% - 7.60, $LSD_{0.05}$ – 0.6550)

4.1.2.3 Interaction effect of germplasm and waterlogging on number of leaves

The influence of waterlogging on the number of leaves plant^{-1} was found significantly different. Waterlogging condition adversely affected the production of leaf number in Mungbean plants. Higher numbers (11) of leaves were found at control in green diamond and lower (5) one was found at treatment in Crystal and Celera germplasm which was 8 and 8~ 9 in number at control.

Table 2: Interaction effects of germplasms and waterlogging on number of leaves

Germplasm × Treatments	Leaf no. at 38 days after waterlogging stress
Green Diamond × Control	11 a
Crystal × Control	8 c
Satin × Control	9 b
Celera × Control	8.333 bc
Green Diamond × Waterlogging	4.666 d
Crystal × Waterlogging	5 d
Satin × Waterlogging	4.666 d
Celera × Waterlogging	5 d
CV%	7.60
$LSD_{(0.05)}$	0.431

4.1.3 Leaf Length (cm)

4.1.3.1 Effects of waterlogging on leaf length (cm) in Mungbean

Difference between treatments on leaf length was found significant at the growth stages of Mungbean. Higher length (9.86 cm) of leaf was observed in control situation. The lower leaf length measured after facing waterlogging condition in a same day and it was 3.9 cm. Both stresses, waterlogging and high water deficit reduced significantly the total biomass of faba bean (*Vicia faba*) plants. Water deficit level (50% FC) significantly reduced roots fresh and dry weights more than low water deficit level (75% FC) as compared to control plants. Whereas, roots dry weight of flooded treatment was seems higher and this sometimes occurs at least in part as the result of initiation of several new lateral roots under flooding condition on the sub- merged part of shoot.

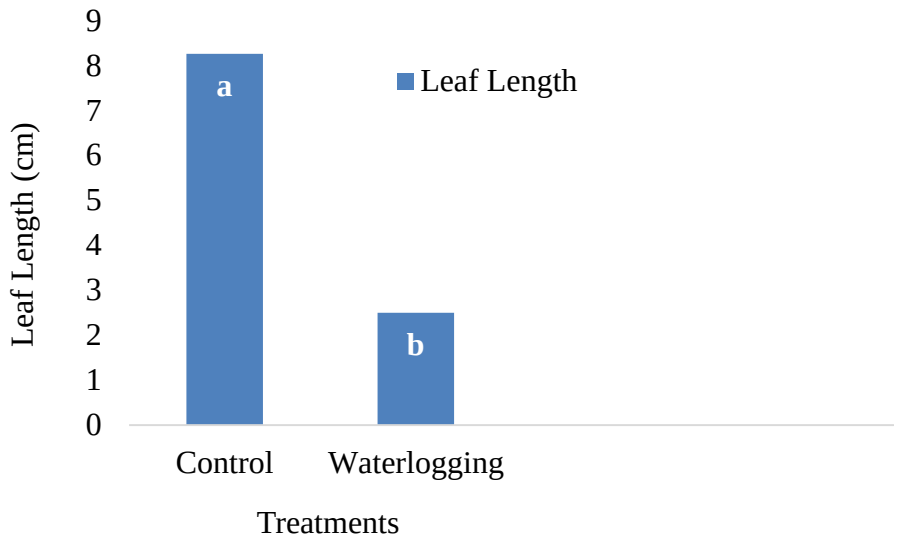

Figure 5. Effects of waterlogging on leaf length (cm) in Mungbean

4.1.3.2 Effect of Germplasms on leaf length (cm) in Mungbean

Significant variation among the germplasms was observed in reduction of leaf length (Figure 6). With waterlogging stress the highest leaf length observed in Green Diamond which was 7.566 cm and it was reduced leaf length from control environment. The lowest leaf length observed from Germplasm-3 named Crystal (3.9 cm). According to reduction of leaf length the series of germplasm is Green Diamond > Satin > Celera > Crystal.

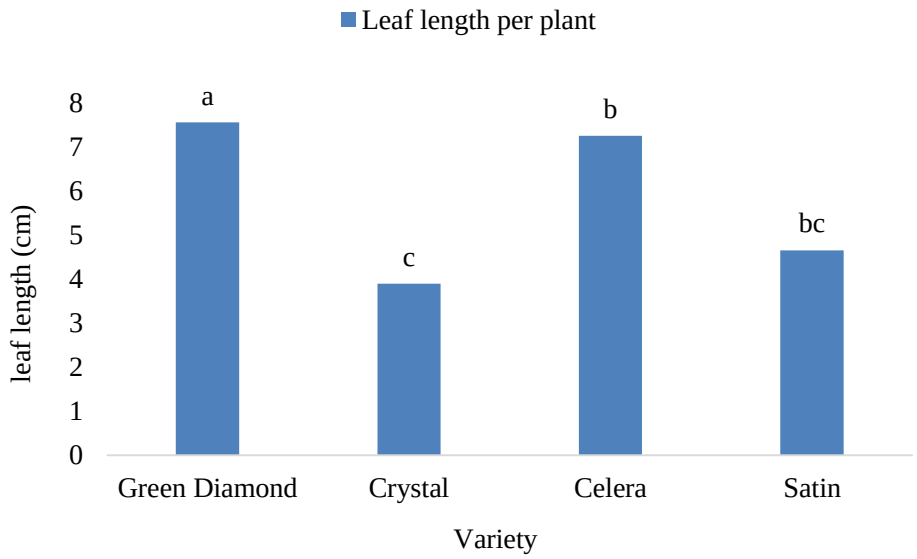

Figure 6. Effect of germplasms in leaf length (cm) at 38 DAS after waterlogging, (Here, $LSD_{(0.05)}$ -0.276, CV% 4.80)

4.1.3.3 Interaction effects of germplasms and treatments on leaf length (cm)

The soil waterlogging-germplasms interaction on leaf length was found significantly different at the growth stages of Mungbean (Table 3). Control treatment produced the higher leaf length plant than those of waterlogging plants after termination of waterlogging. The highest leaf length (9.87 cm) was measured at control situation in Crystal and lowest was measured in same germplasm which is (3.9 cm). This was the most significant difference for waterlogging stress. Others germplasms were Green Diamond, Satin, Celera which contained leaf length respectively in control and treatment 9.15 cm, 7.7cm, 6.333cm and 7.566 cm, 7.2666 cm, 4.666 cm. At maturity, the leaf length $plant^{-1}$ of both control and waterlogging plants were lower than those of leaf area produced during pre-flowering or pod filling stage. The result also indicates that leaf length reduce for the waterlogging condition among this four germplasm. Leaf length $plant^{-1}$ of all the waterlogging genotypes were reduced by 50% relative to control. Umaharan *et al.* (1997) reported that leaf area development during the vegetative phase showed significant differences between waterlogging and control in cowpea plants. This might be due to the senescence and abscission of lower leaves at maturity. Similar result was also observed by Islam (2005).

This might be due to the senescence and abscission of lower leaves at maturity. Similar result was also observed by Islam (2005). Acclimation in waterlogging environment have been similarly reported in soybean by Bacanamwo and Purcell (1999). Solaiman *et al*. 2007; Pociecha *et al*. 2008; Celik and Turhan (2011) reported that 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.

Table 3. Interaction Effects of Germplasm and Treatments on leaf length (cm)

Germplasm × Treatment	**Leaf length at 38 days after waterlogging stress**
Green Diamond × Control	9.15 b
Crystal × Control	9.87 a
Satin × Control	7.7 c
Celera × Control	6.333 d
Green Diamond × Waterlogging	7.566 c
Crystal × Waterlogging	3.9 f
Satin × Waterlogging	7.2666 c
Celera × Waterlogging	4.666 e
CV%	4.80
LSD$_{(0.05)}$	2.67

4.1.4 Chlorophyll content (SPAD Unit)

4.1.4.1 Effect of waterlogging on chlorophyll content (SPAD Unit)

The effect of waterlogging on chlorophyll content was statistically significant (Figure 7). Waterlogging caused reduction in chlorophyll content of leaf. Higher chlorophyll was found in 50.076 (SPAD unit) in which measured in control condition and lower amount of chlorophyll was contained 29.53 (SPAD unit) in waterlogging condition and all the measured chlorophyll contained data were reduced in waterlogging than control.

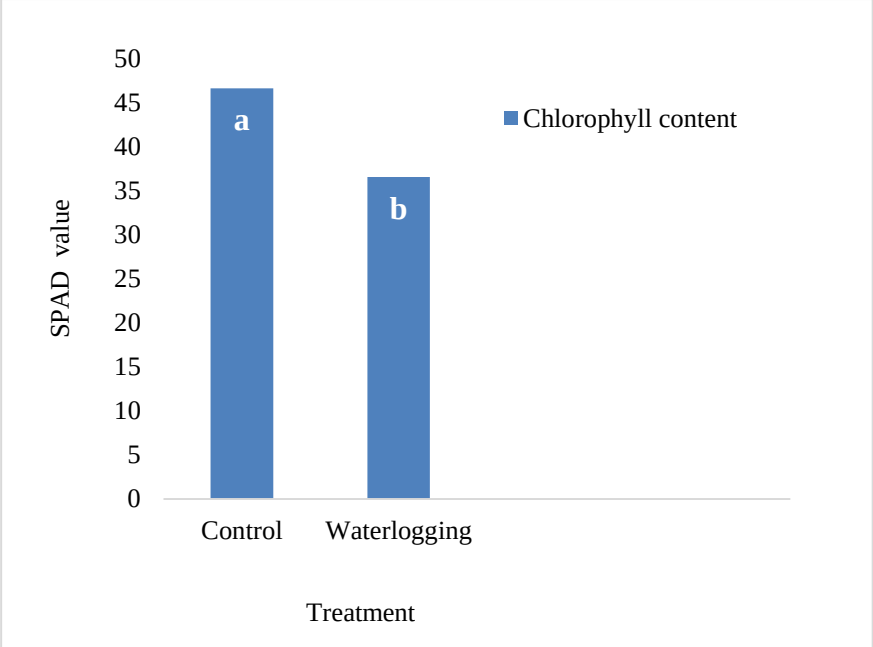

Figure 7. Effect of waterlogging on chlorophyll content (SPAD Unit)

As duration of waterlogging stress increases, leaf yellowing starts followed by wilting of the plant. Hence, chlorophyll content reduced significantly in all the genotypes in response to stress. Chlorophyll is the most important pigment required for photosynthesis. Its loss under waterlogging is well documented and is visible by increased yellowing of leaves. Chlorophyll content reduced in all the genotypes, but tolerant one sustained the stress by relatively maintaining the chlorophyll content, according to a similar thesis on blackgram (legume family) prepared by Ruchi *et al.* at 2010.

4.1.4.2 Effect of germplasms on chlorophyll content (SPAD Unit)

Effect of waterlogging on experimental germplasm was statistically significant (Figure 8). At vegetative stage the highest chlorophyll after facing waterlogging stress was measured in Crystal in SPAD unit 46.03 and lowest 29.53 in satin. Germplasm-2 named Crystal content more chlorophyll which wasn't hampered much in chlorophyll content, its leaf length was higher than any other germplasm. Loss of chlorophyll content caused chlorosis of leaves that later turned into necrosis. These adverse effects finally caused senescence and plant death (Sairam *et al.*, 2002).

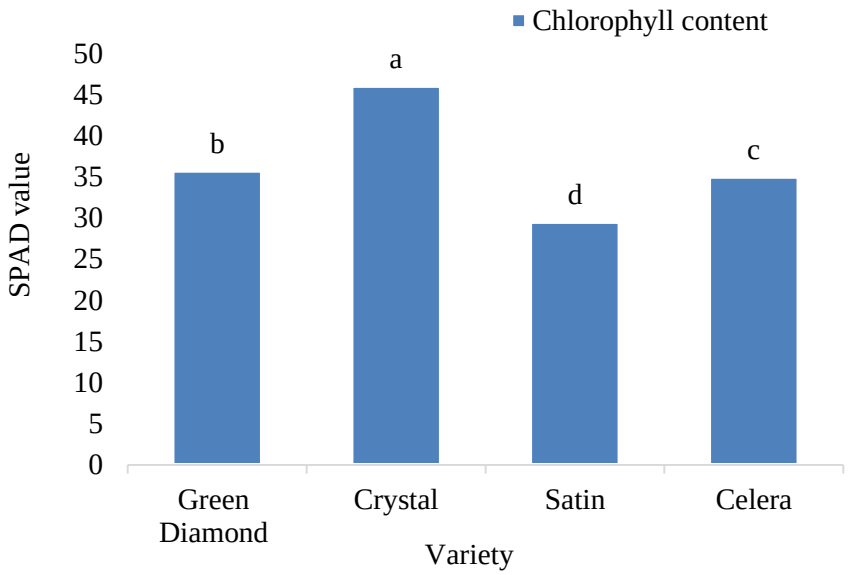

Figure 8. Effect of Germplasms on chlorophyll content (SPAD Unit), (Here, CV% - 2.34, $LSD_{0.05}$ – 1.2059)

4.1.4.3 Interaction effects of germplasms and waterlogging on chlorophyll content

The effect of waterlogging on chlorophyll content was statistically significant (Figure 9). Waterlogging caused reduction in chlorophyll content of leaf. Highest chlorophyll was contained in Crystal (50.076) which measured in waterlogging condition 35.733. Lower amount of chlorophyll content was measured in Satin (29.53) in waterlogging condition and it was 46.016. After waterlogging stress chlorophyll content rate decreased. So, the result of this discussion is waterlogging reduced the chlorophyll content rate of Mungbean.

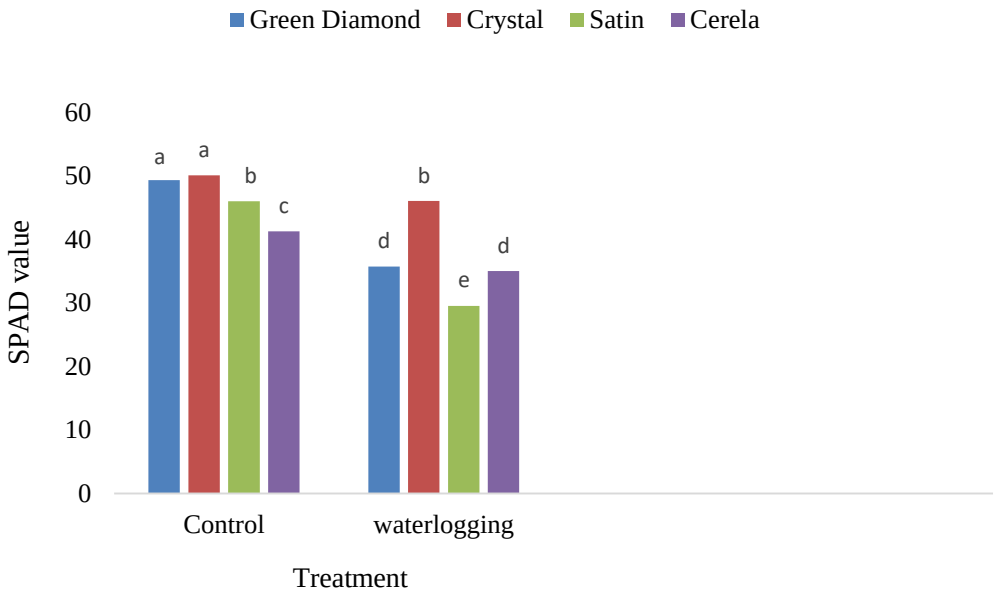

Figure 9. Interaction effects of germplasm and waterlogging in chlorophyll content after 39 DAS of waterlogging (Here, $LSD_{0.05}$ – 0.693 at CV% 3.11)

Chlorophyll was measured at 39 DAS on the earliest fully-expanded leaves of 1 plant in each pot, after observance the leaves in the dark for 30 min prior to measurement by means of plant efficient. Measurements were occupied at 50% light intensity and the exposure time was set at 5 second. Green Diamond (V_1), Crystal (V_2), Satin (V_3) and Celera (V_4) were contained respectively 49.303, 50.076, 46.016, and 41.253 in SPAD unit in control. On the other hand after facing waterlogging stress chlorophyll content of each germplasm was reduced extremely. It was measured after waterlogging in 4 germplasms respectively 35.733, 46.03, 29.53, and 35.016 SPAD. Highest reduction percentage of chlorophyll content observed in Satin (V_3), and less reduction detected in Crystal (V_2) followed by Celera (V_4).

4.1.5 Days required to turn into normal condition of plant after waterlogging

After 72 hours waterlogging, plants became wilted. Each germplasm took different time duration to turn into normal condition from wilting which is significant. To turn into normal plant condition from wilting, Celera and Green Diamond being normal in 31~32 DAS. On the other hand Crystal took 36 DAS and Satin took 34 DAS (Figure 10). Some leaves were abscised for more water uptake. Plants had to operate their energies into renewed pigment production, and re-greened chlorotic leaves at the onset of recovery (Smethurst *et al.*, 2005). A previous study showed that pea and grasspea did not recover

within 10 days after termination of waterlogging (Solaiman *et al.*, 2007). Presumably, in this study, a longer recovery period led to the different result. Relatively waterlogging-tolerant genotypes had an altered root distribution (i.e. near the soil surface) pattern while grown in waterlogged conditions as demonstrated by shallow root system-root length was short (~100 mm) in waterlogged plants. But the overall root dry weight was similar for both control and waterlogging.

Plate 5. Wilting situation in 72 hours waterlogging condition

However, there are disadvantages to the formation of the lateral roots Armstrong *et al.* (1983) in pea and Malik *et al.* (2001) in wheat demonstrated that the lateral roots consumed O_2 which restrict O_2 movement through aerenchyma in the primary root; thus restrict root penetration into the deeper zone.

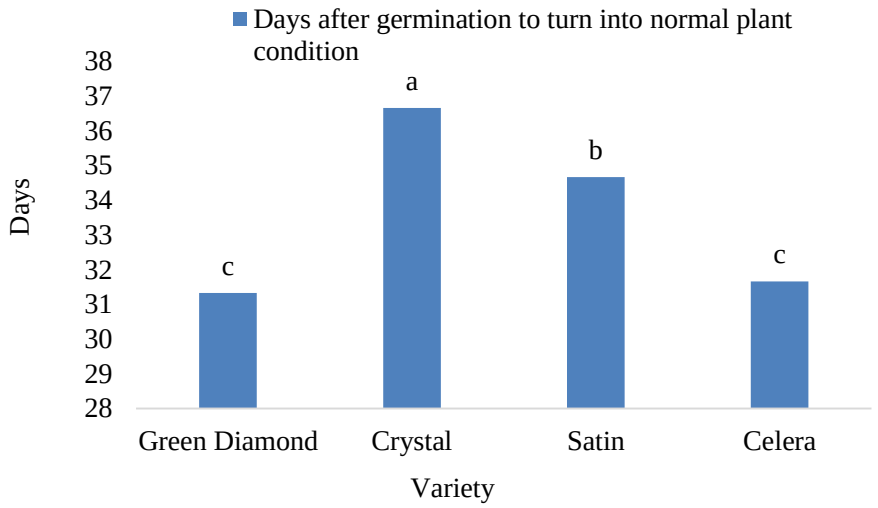

Figure 10. Required days to turn into normal condition for germplasms

Plants maintained growth during the stress periods; presumably, the lateral roots become functional roots as demonstrated for pasture legumes (Gibberd *et al.* 1999). It is promising that during the recovery period the shallow root resumed growth and reached the same length as in the drained control, allowing access to soil moisture at depth as the soil profile dries later in the season (Malik *et. al.*, 2015).

4.1.5.1 Waterlogging effects on new leaf initiation

New leaf initiated after waterlogging condition and plants being vigorous day after day. The first day of initiated leaf was difference among germplasms which was statistically significant (Figure 11). Firstly in Green diamond leaf initiated at 39.666 days after germination that was after 12 days of waterlogging. Then in Celera, it took 40.333 (13 days after waterlogging condition). Others two germplasm Crystal and Satin took 43.333 (16 days after waterlogging condition) and 45.666 (19 days after waterlogging). Leaf initiation increase photosynthesis rate and its must be effective for yield.

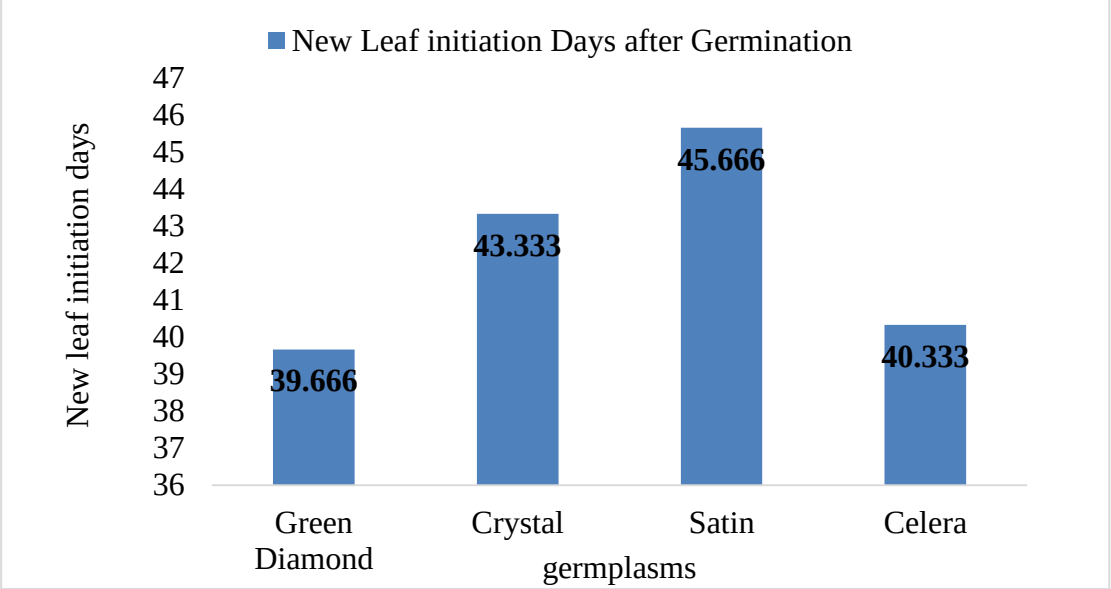

Figure 11. Required days to initiation of new leaf after waterlogging condition (Here CV% 1.42, LSD $_{(0.05)}$ – 0.490)

4.1.6 50% Flowering

4.1.6.1 Effects of waterlogging on 50% flowering

Significant variation among control and waterlogging was observed in delaying 50% flowering. In control the 29 days required for 50% flowering and highest days (47.66) required for 50% flowering in waterlogged pot (Figure 12). 72 hours waterlogging delayed days to 50% flowering by 10-12 days than that of non-waterlogging control. High rainfall and indeterminate growth habits interruption flower primordial establishment as well as indeterminate growth habits that increasing plant height gradually eventually delayed maturity. Earlier germination and emergence rate in priming Mungbean and maize seed over the control was observed by Umbair *et al.* (2010) and Dezfuli *et al.* (2008).

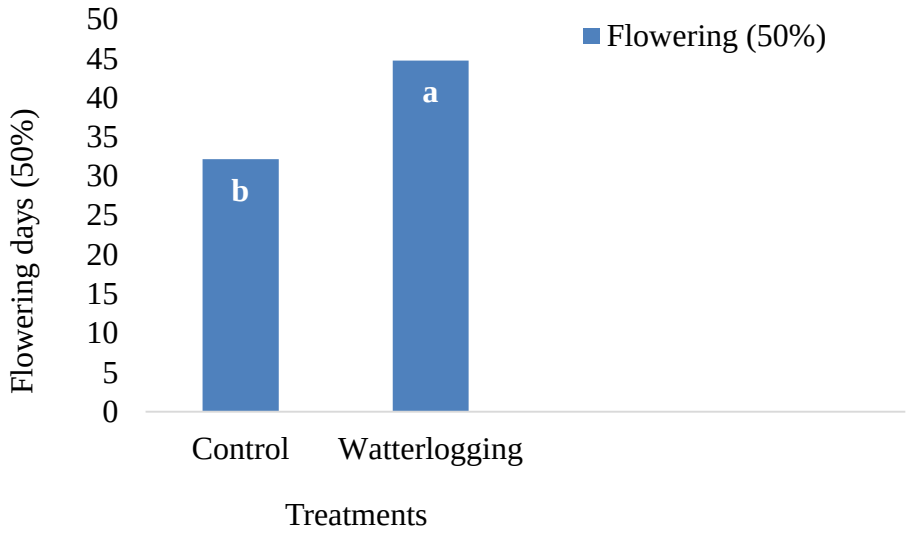

Figure 12. Treatment effects on 50% flowering in Mungbean

4.1.6.2 Effects germplasms for 50% flowering

Effects of waterlogging among germplasms are significant according to statistical analysis. The shortest duration to 50% flowering was required in Celera (29 days) followed by Green diamond (31 days). After waterlogging stress plants turned back to normal condition from wilting and delay flowering occurred. Then Germplasms Green diamond, Crystal, Satin and Celera took respectively 43, 47.33, 47.67 and 41 (Figure 13). Celera took lowest days for flowering in both control and waterlogging.

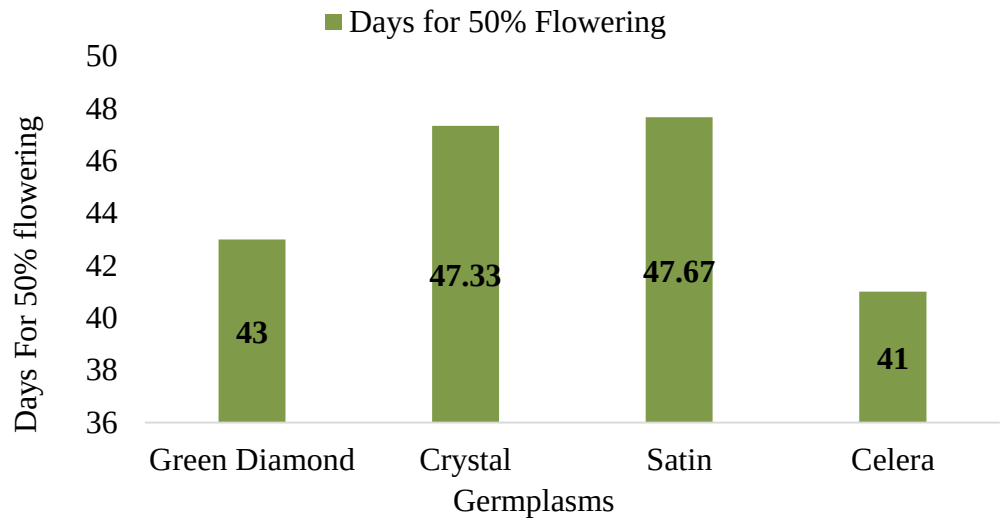

Figure 13. Days for 50% flowering among germplasms, (Here CV% 2.01, LSD $_{(0.05)}$ -7.333

4.1.6.3 Interaction effects of germplasms and waterlogging on 50% flowering

Germplasm-treatment interaction on days to 50% flowering was found significantly different (Table 4). Soil waterlogging for 72 hours significantly delayed days to 50% flowering than control. Crystal and Satin took 34.333 and 34.33 days to 50% flowering, respectively. Effect of 72 hours waterlogging on days to 50% flowering of 4 selected Mungbean genotype and they took 10-12 more days than control environment. Soil waterlogging for 72 hours days significantly delayed days to maturity. Indeterminate plants flower until some environmental condition triggers them to stop. Too cold, too hot, too dry or too wet can all trigger indeterminate plants to stop flowering. Plant breeders have long known that some plants are indeterminate or determinate and refuse to change, while other plants can be modified away from their natural flowering habit. Similarly Kumar *et al.* (2013) reported that both tolerant and sensitive Mungbean genotypes showed the inhibition of flowering and pod setting under waterlogging.

Table 4. Effect of 72 hours flooding on days to 50% flowering of selected mungbean germplasms

Germplasms × Treatments	**Days of 50% flowering**
Green Diamond × Control	31 e
Crystal × Control	34.3333 d
Satin × Control	34.3333 d
Celera × Control	29 f
Green Diamond × waterlogging	43b
Crystal × waterlogging	47.3333 a
Satin × waterlogging	47.6667 a
Celera × waterlogging	41 c
CV%	2.63
$LSD_{(0.05)}$	**NS**

4.2. Effect of waterlogging on yield and yield contributing characters among mungbean germplasms

4.2.1 Pod number

4.2.1.1 Effects of waterlogging on pod number

Waterlogging condition resulted significantly reduction in number of pods per plant. Higher (14) number of pods per plant was obtained from control and lower number of pods (9.5) per plant was obtained from waterlogging (Figure 14).

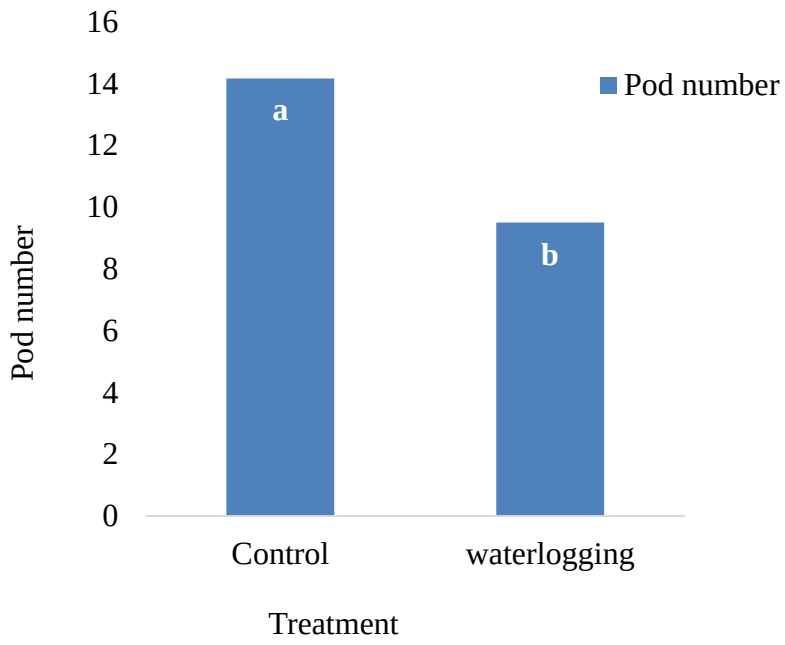

Figure 14. Effects of waterlogging on pod number

4.2.1.2 Effect of waterlogging on pod number among germplasms

Among four germplasm named Celera was obtained highest number of pod which is 12.333 in number after facing waterlogging stress (Figure 15). And other germplasms Green Diamond, Crystal and Satin were obtained 9.333, 7.666 and 8.666 in number of pod respectively. Most pod producing germplasm was Celera in control and waterlogging, and the reduction of pod number was very prominent.

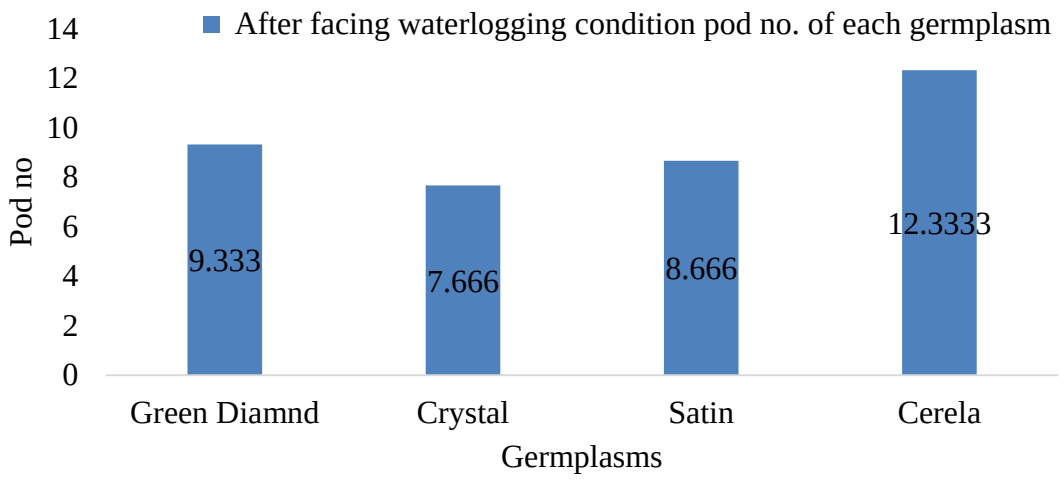

Figure 15. Effects of waterlogging in pod number on mungbean germplasms, (Here, CV% - 7.83, LSD $_{0.05}$ – 1.01809)

4.2.1.3 Interaction effects of germplasms and treatment on pod number

The number of pods per plant was found significantly different for waterlogging. The highest (20) number of pods per plant was obtained from control (Table 5) in germplasm Celera. The lowest number (7.666) of pod was obtained from germplasm named Satin after waterlogging from per plant.

Table 5. Effects of waterlogging on pod number in germplasms and treatments

Germplasm × Treatment	Pod number
Green Diamond × Control	12.333 c
Crystal × Control	10.333 d
Satin × Control	14 b
Celera × Control	20 a
Green Diamond × waterlogging	9.333 de
Crystal × waterlogging	7.666 f
Satin × waterlogging	8.666 ec
Celera × waterlogging	12.33333 c
CV%	7.33
$LSD_{(0.05)}$	0.712

Soil waterlogging for 72 hours significantly reduced the number of pods plant^{-1} irrespective of genotypes. Similar result was also observed in legumes by Solaiman *et al.*, (2007), Pociecha *et al.* (2008) under Waterlogging condition. Islam (2005) reported that waterlogging significantly reduced pods plant^{-1} in Mungbean and 36% more pods were produced in control plants than waterlogged plants.

4.2.2 Pod Length (cm)

4.2.2.1 Effects of waterlogging on pod length (cm)

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 7.953 cm (Figure 16). Lower pod length was measured in waterlogging treatment 6.06 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).

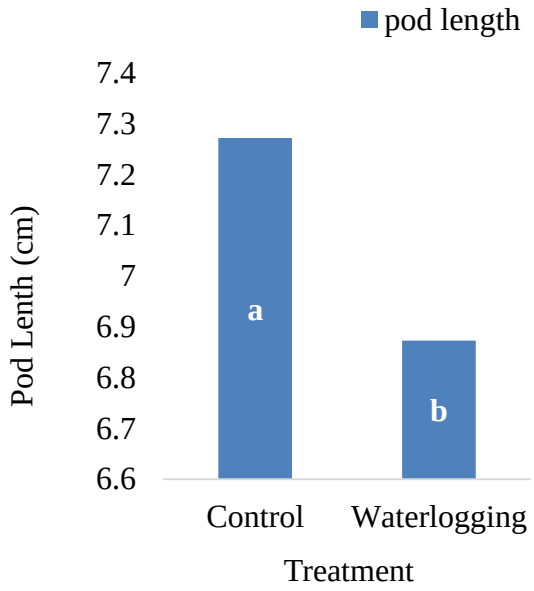

Figure 16. Effects of waterlogging on pod length (cm) of mungbean

4.2.2.2 Effect of waterlogging among mungbean germplasm

Effect of waterlogging stress on different genotypes was statistically significant (Figure 17). Among four germplasms, Crystal belonged to highest (7.553 cm) pod length with waterlogging stress. Lowest pod length (6.06 cm) was measured from Green Diamond. In figure 17, Bar graph represent the reduction of pod length with varietal comparison for waterlogging stress. Series of germplasms according to reducing pod length Crystal > Satin > Celera > Green Diamond.

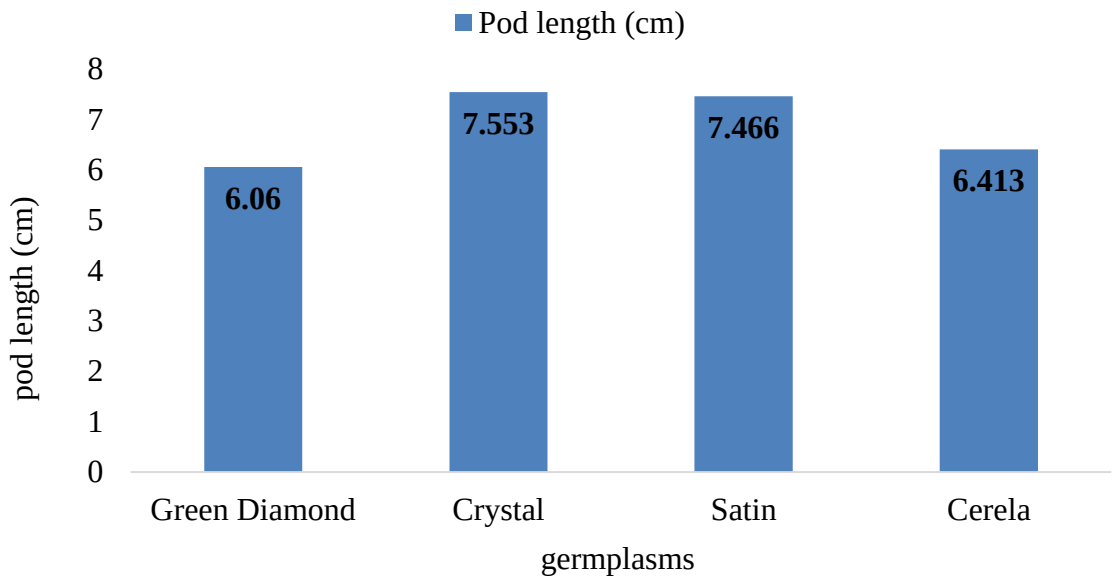

Figure 17. Effect of germplasm on pod length (cm) with waterlogging stress, (Here CV% 3.09, and LSD $_{(0.05)}$ – 0.1734)

4.2.2.3 Interaction effect of germplasms and waterlogging on pod length (cm)

Pod length is one of the most important yield contributing characters in Mungbean. Germplasms showed significant difference in pod length (figure 18). The longest pod length (9.87cm) was recorded in V_1 (Green Diamond). The shortest pod length (3.9 cm) was observed in V_2 (Crystal) in Waterlogging. Pod length differed from germplasms to germplasms. The possible reason of this difference could be the genetic make-up of the germplasms. Other's germplasms pod length decrease for the effect of 72 hours waterlogging in vegetative stage of Mungbean plant.

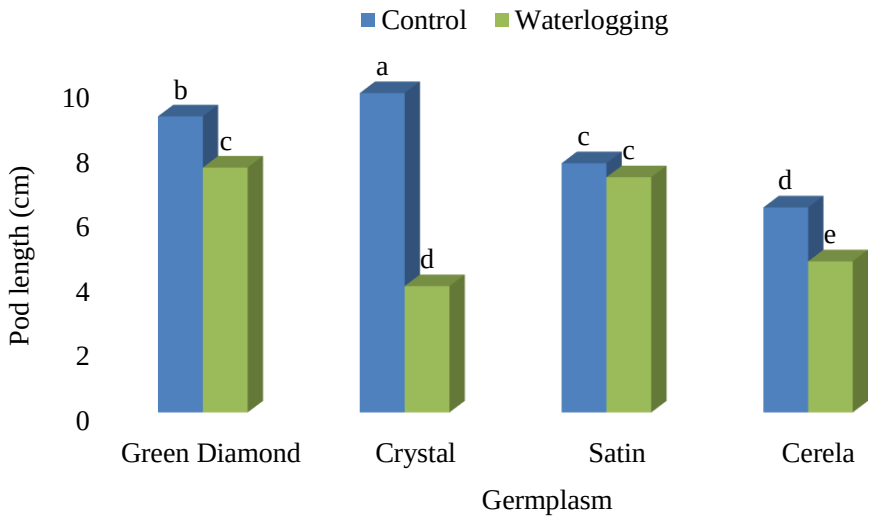

Figure 18. Interaction between germplasm and waterlogging on pod length (cm), here CV% 4.80, (LSD $_{(0.05)}$ -NS),

In a column same letter(s) do not significantly differ at 0.05 level of probability.

4.2.3 Number of seeds per pod

4.2.3.1 Effects of waterlogging on number of seeds per pod

The number of seeds per pod was significantly affected due to the different germplasms at different days after sowing. Higher number of seeds (10.5) per pod counted from control and lower number of seeds (9.5) per pod counted from control.

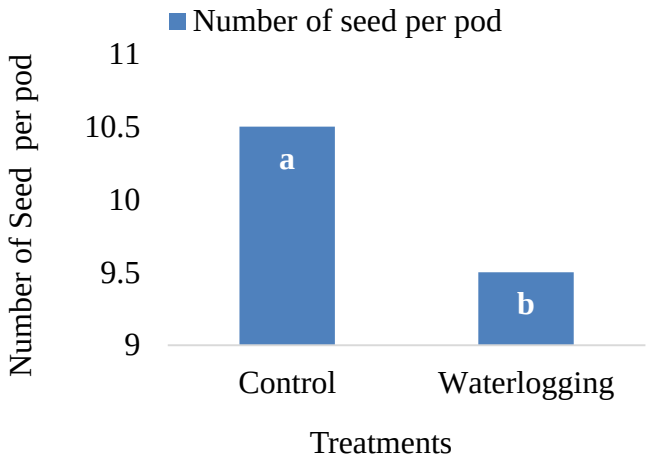

Figure 19. Effects of waterlogging on number of seeds per pod in mungbean

The mean value of control and waterlogging treatments are respectively 10.5 and 9.5 for number of seed per pod.

4.2.3.2 Effect of germplasms on number of seeds per pod

Among the Germplasms, number of seeds pod^{-1} was found significantly difference (Figure 20). The highest number of seeds pod^{-1} (11) in crystal and the lowest (8.666) was in Green Diamond and Satin. The highest number of seed per pod reduced in after waterlogging treatment. On the other hand Celera (V_4) content statistically same number of seeds per pod (11) in both treatments.

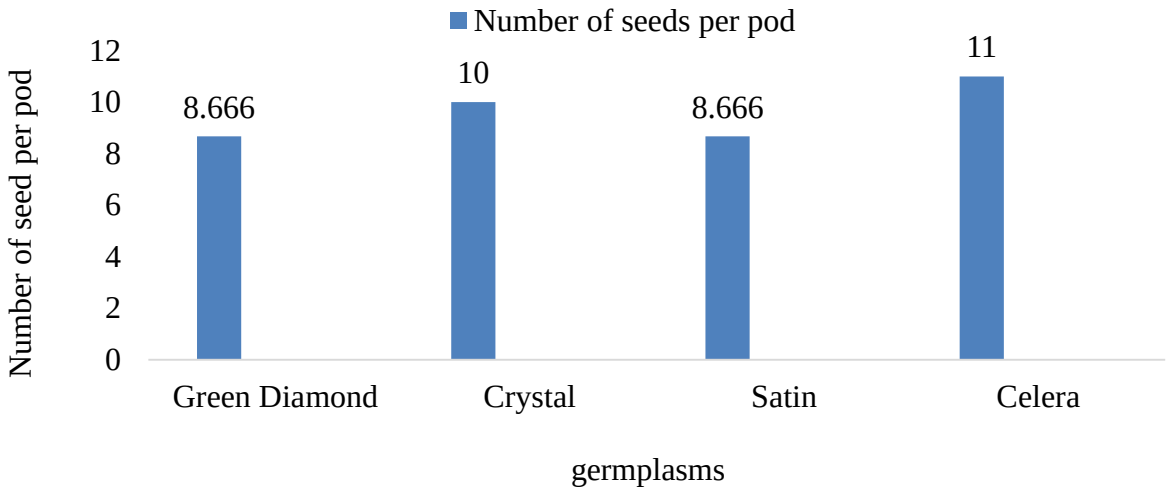

Figure 20. Effect of germplasms on number of seeds per pod, (here CV% 3.92, LSD $_{(0.05)}$ - 0.3040)

4.2.3.3 Interaction effects of germplasms and waterlogging on number of seed per pod

Significant differences were recorded between treatments and germplasms with regards to number of seeds per pod. Number of seeds per pod recorded in Mungbean germplasms as influenced by waterlogging are presented in Table 6. Waterlogging reduced the number of seeds per pod significantly over the control.

Table 6. Interaction effects of germplasm and waterlogging on number of seed per pod

Germplasm × Treatment	Number of seed per pod
Green Diamond × Control	10 ab
Crystal × Control	11 a
Satin × Control	10 b
Celera × Control	11 ab
Green Diamond × waterlogging	8.666 c
Crystal × waterlogging	10 b
Satin × waterlogging	8.666 c
Celera × waterlogging	11 a
CV%	4.15
$LSD_{(0.05)}$	0.339

Similar results were also reported in greengram (Laosuwan *et al*., 1994, and Ahmed *et al.* 2002) and in winter rape (Zhou *et al.*, 1997). The genotypes were also significantly varied for number of seeds per pod. Among the genotypes tested Celera recorded highest number of seeds (11) per pod followed by and the lowest number of seeds (8.666) per pod was recorded by Green Diamond facing waterlogging. Green Diamond contained 10 number of seeds per pod in control. Without Celera all other germplasms contained number of seeds per pod reduced in the waterlogging condition (Table 5). Similar differences in genotypes were also observed in greengram (Laosuwan *et al*., 1994 and Yadav and Saxena, 1998).

4.2.4 Hundred seed weight (g)

4.2.4.1 Effects of waterlogging on hundred seed weight (g) in mungbean

The effect of waterlogging on 100 seed weight (g) was varied significantly different. Hundred seed weight represents grain size of a germplasm. Higher 100 grain weight

(5.886g) was obtained from control. Lower 100 grain weight (2.85g) was recorded from waterlogged condition. Seed size was reduced with increased waterlogging.

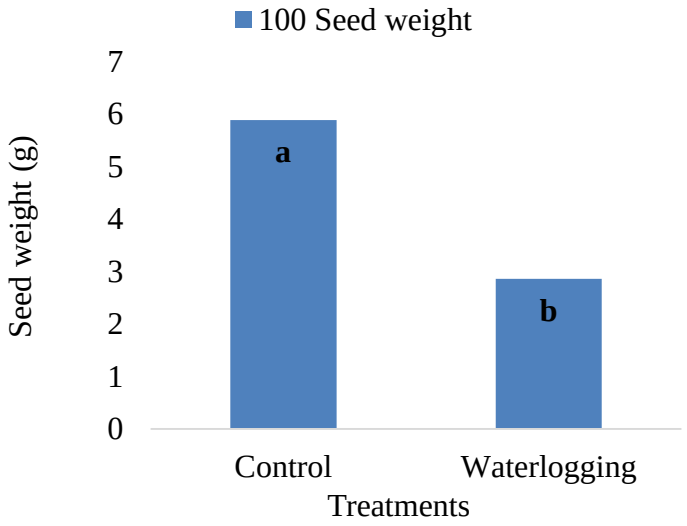

Figure 21. Effects of waterlogging on hundred seed weight in selective mungbean germplasm

4.2.4.2 Effects of germplasms on hundred seed weight (g)

Among the germplasms 100-seed weight was significantly difference ($P<0.05$). Among the germplasms, Celera produced the maximum (3.573 g) seed weight which was highest weight and Crystal produced the lowest (2.276 g) seed weight with 72 hours waterlogging stress (Figure 22). Gupta *et al*. (1978) reported that 100-seed weight, plant height and days to maturity were influenced by additive gene action.

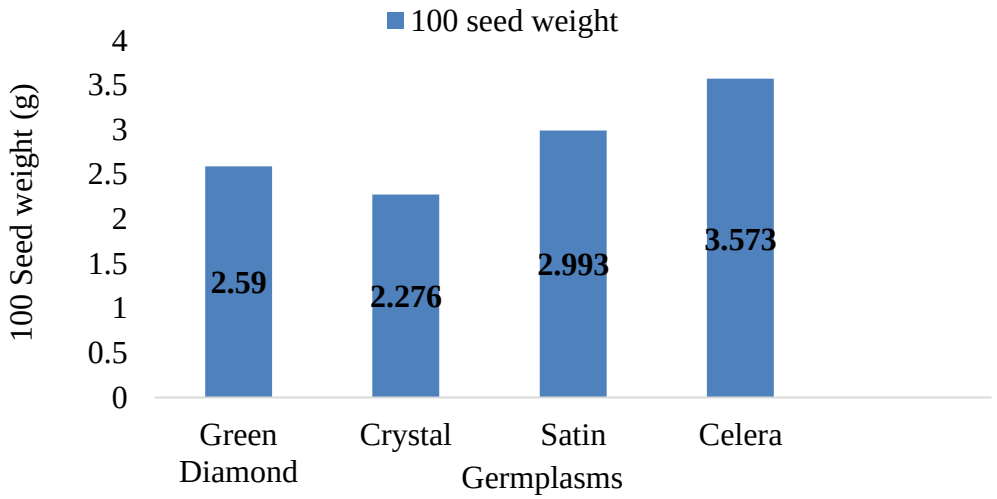

Figure 22. Effects of germplasms on hundred seed weight (g), (Here CV% - 7.17, LSD $_{(0.05)}$ – 0.255)

Such inhibition may also be due to adverse effects of waterlogging on water and mineral uptake (Hocking *et al.*, 1987).Similar results were also reported in greengram (Laosuwan *et al*., 1994, Yadav and Saxena, 1998, Ahmed *et al*., 2002).

4.2.4.3 Interaction effects of treatment and germplasm on hundred seed weight (g)

The interaction effect of waterlogging situation and genotypes on 100-seed weight was also varied significantly (Table 7). The highest 100-seed weight was found in Crystal (8.006g) at control condition and in this same germplasm 100-seed weight was measured lowest value (2.276 g) at waterlogging stress. Green Diamond and Celera contained less reduction of 100-seed weight from control to waterlogging, this was respectively in control 3.973g, 3.71g and after waterlogging stress 2.59 g, 3.573 g. Genotypic variation in 1000-seed weight was observed by Takele *et al.*, (1995) in Mungbean that also supported the present experimental results.

Table 7. Interaction effects of germplasms and waterlogging on hundred seed weight in Mungbean (g)

Germplasm × Treatment	100 seed weight (g)
Green Diamond × Control	3.973 b
Crystal × Control	8.006 a
Satin × Control	7.85 a
Celera × Control	3.71 b
Green Diamond × Waterlogging	2.59 cd
Crystal × Waterlogging	2.276 d
Satin × Waterlogging	2.993 c
Celera × Waterlogging	3.573 b
CV%	7.17
LSD$_{(0.05)}$	0.255

4.2.5 Hundred seed dry weight (g)

4.2.5.1 Effects of waterlogging on hundred seed dry weight (g)

Seed dry weight was found significantly difference, influenced by waterlogging. The data on the effect of waterlogging on 100 seed dry weight is given in Figure 23. Similar results were observed in pigeon pea (Takele and McDavid, 1995). The genotypes tested also significantly varied for seed dry weight at all crop growth stages. Among the genotypes tested, Crystal recorded highest seed dry weight (7.25g) in control. The lowest seed dry weight (2.036g) was recorded by Crystal from waterlogged stress.

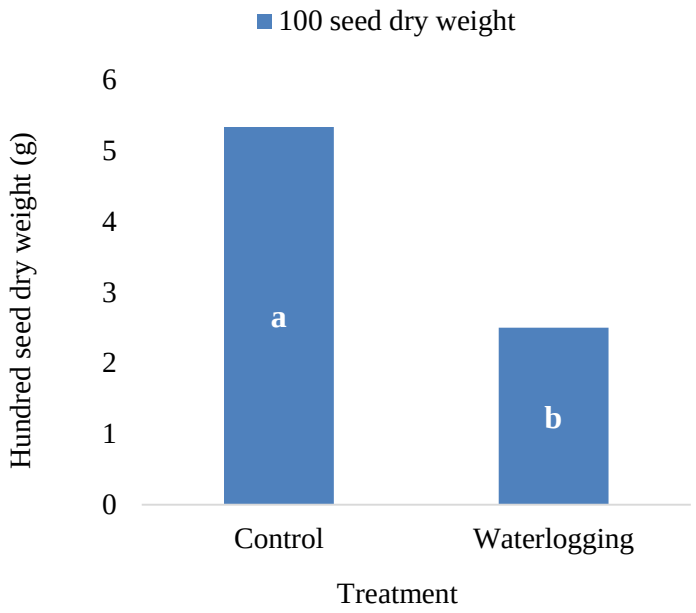

Figure 23. Effects of waterlogging on hundred seed dry weight (g)

4.2.5.2 Effects of germplasms on hundred seed dry weight (g)

The effect of waterlogging on 100 seed dry weight (SDW) (g) was varied significantly. Hundred seed dry weight represents grain size of a germplasm. Highest 100-seed dry weight was dignified from V-4 Celera (3.2 g) after waterlogging (T_2) condition. In control (T_1) highest seed dry weight belonged to Crystal (7.25 g). But after fronting waterlogging stress crystal comprised 2.036 g SDW for 100 seeds. On the other hand Celera comprised 3.36 g SDW and 3.2 g SDW respectively from control (T_1) and waterlogging stress (T_2). In Celera, the water loss reduction rate was less than any other genotype used in experiment.

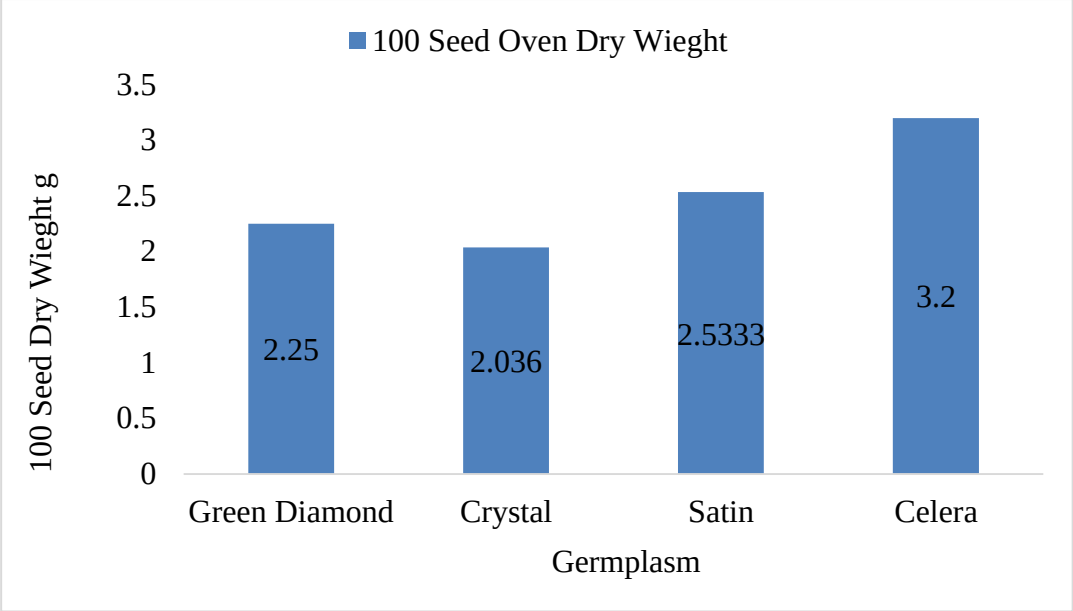

Figure 24. Effects of germplasms on hundred seeds dry weight (g) in mungbean

4.2.5.3 Interaction effects of germplasm and treatments on hundred seed dry weight (g)

The interaction effect of waterlogging and germplasms in relation to 100 seed dry weight (SDW) per plant was found significantly difference ($P<0.05$) (Table 8). The maximum 100 SDW (7.25g) was observed in Crystal at control (T_1) and the minimum 100 SDW (2.036g) was observed in same germplasm Crystal followed by Green Diamond (2.25 g).

Table 8. Interaction effects of germplasm and treatments on hundred seeds dry weight (g)

Germplasm × Treatment	Oven dry weight (g)
Green Diamond × Control	3.596 b
Crystal × Control	7.25 a
Satin × Control	7.12 a
Celera × Control	3.366 b
Green Diamond ×Waterlogging	2.25 c
Crystal × Waterlogging	2.036 c
Satin × Waterlogging	2.533 c
Celera × Waterlogging	3.2 b
CV%	4.80
LSD$_{(0.05)}$	0.253

4.2.6 Seed moisture percentage (%)

4.2.6.1 Effects of waterlogging on moisture percentage (%)

Significant effect of waterlogging stress was found on Moisture percentage (MP %) (Figure 25). 100 seed weight was taken in both fresh and dry condition, then moisture percentage was calculated. Higher (53.333 %) seed MP % was obtained from control (T_1) treatment and lower (32.167%) from waterlogging (T_2) condition. Pulses with large seeds (field pea and chickpea) continue to breathe or respire after being harvested as moisture equalizes throughout these large seeds. This causes them to go through a sweat period for several weeks after harvest, which raises the temperature and moisture content of the stored grain, producing favorable conditions for mold growth. The moisture content was believed not to directly influence the shelf life of mung bean seeds during the storage process, however this parameter is believed having contribution in such away to the viability of seeds. The moisture content of the mung bean seeds during storage related to predetermine seed quality standards. The percentage of seed moisture content has increased but still within the limits of seed

quality requirements. The quality requirements of mungbean seeds is a moisture content not higher than 11%. Therefore the level of moisture content during storage is very important to minimize the reduction of mung bean seeds (Fan *et al.* 2016)

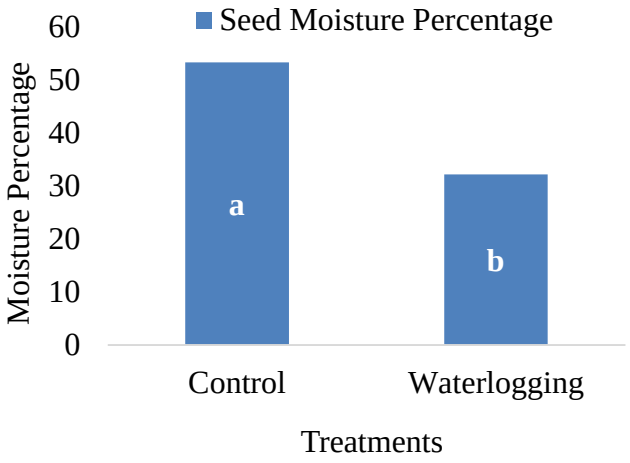

Figure 25. Effects of waterlogging on moisture percentage in Mungbean

4.2.6.2 Waterlogging effects on MP % among germplasms

Among the germplasms individual moisture percentage was significant by differences ($P<0.05$). All the experimental genotype, Green Diamond, Crystal, Satin, and Celera was contained MP % respectively 35%, 72%, 73.333%, and 33% in control (T_1) and it was respectively reduced in waterlogging (T_2) 28%, 27.666%, 47%, and 26%. After waterlogging stress MP % reduced from seed more than control (T_1).

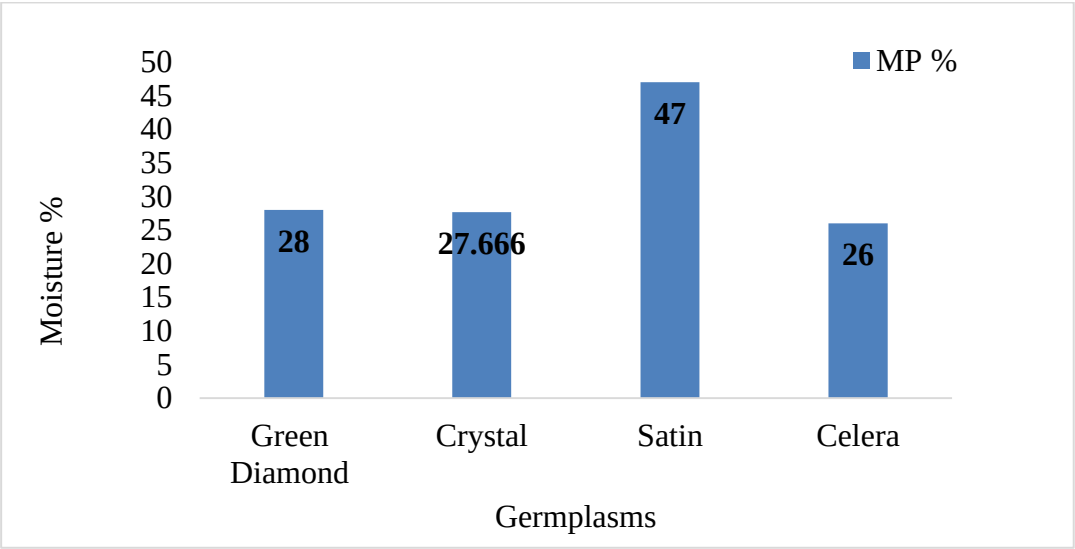

Figure 26. Effects of germplasms on moisture percentage (%) in mungbean

4.2.6.3 Interaction effects of germplasm and treatments on moisture percentage (%)

The interaction effect on seed moisture percentage between germplasms and waterlogging treatment was found significantly difference (Table 11). It was observed that the highest percentage of moisture in germplasm Satin 73.333% in control (T_1) and it became 47% in waterlogging (T_2) followed by Crystal, Green Diamond, and Celera. Minchin et al. (1978) observed severe reduction in biomass (50% of the control) when cowpea plants were flooded in a similar fashion during vegetative phase. Kumar *et al*. (2013) reported that soil flooding in Mungbean reduced total dry matter production and also affected the dry matter partitioning. So, effects of waterlogging on Dry matter reduction induce moisture percentage from seeds and difference is significant statistically.

Table 9. Interaction among germplasm and treatments on seed moisture percentage in mungbean

Germplasm × Treatment	Moisture %
Green Diamond × Control	35 c
Crystal × Control	72 a
Satin × Control	73.333 a
Celera × Control	33 c
Green Diamond × Waterlogging	28 d
Crystal × Waterlogging	27.666 d
Satin × Waterlogging	47 b
Celera × Waterlogging	26 d
CV%	3.68
LSD$_{(0.05)}$	1.5786

4.2.7 Yield per plant (g)

4.2.7.1 Effects of waterlogging on yield per plant (g) in mungbean

The effect of waterlogging on the yield per plant data in Figure 26 indicated that waterlogging in vegetative stage significantly decreased yield per plant. Significant

differences were recorded between waterlogging treatment with regards to seed yield. The higher yield (5.308 g) was recorded at control condition and the lower (1.0283 g) was recorded at waterlogging treatment. Waterlogging decreased the seed yield significantly over the control. The possible reason of this difference might be due to higher number of pod length, seeds per pod. The performance of other germplasms was as midway yielder. Genotypic variation in seed yield was also detected by Borah (1994). Reduction in seed yield under waterlogged condition was due to oxygen deficiency and anaerobic conditions and less root activity. 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 (Hocking *et al*., 1987). 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).

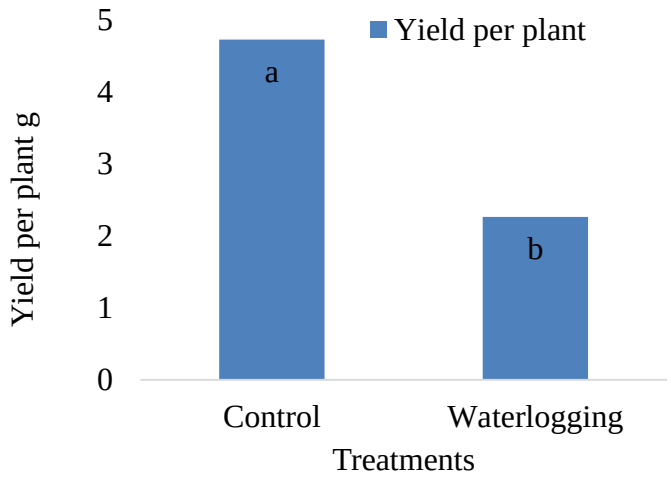

Figure 27. Effects of waterlogging on yield per plant (g) in mungbean

4.2.7.2 Effects of germplasms on yield per plant (g) in mungbean

Among the genotypes, yield per plant was found significantly different (Figure 27). In waterlogging treatment the Celera contained in highest yield (4.1916 g) per plant (Figure 27). The highest yield per plant was measured in Celera (5.3083 g) in control

(T_1) also. The lowest yield obtained from Crystal (1.0283 g) and followed by Green Diamond (1.2358 g) was in waterlogging treatment.

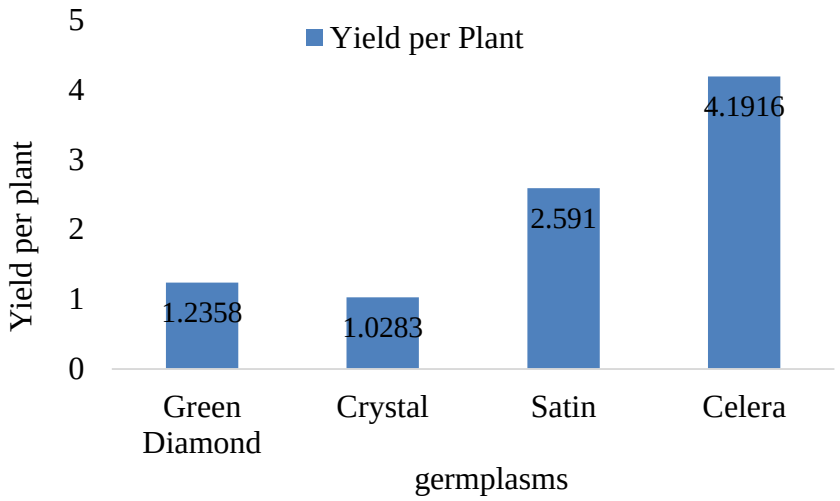

Figure 28. Effects of Germplasm on yield per plant (g) in mungbean, (Here CV% -10.49, $LSD_{0.05}$ - 0.3210)

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 (Palta *et al.*, 2010).

4.2.7.3 Interaction effects of germplasms and treatments on yield per plant (g)

The interaction effect of germplasms and treatments on yield per plant was also varied significantly different (Table 10). The highest was found in Celera (3.0833 g), then satin (5.2 g), Crystal (4.6 g) and Green Diamond (3.80833 g). In Control (T_1) according to yield performance per plant the varietal series is Celera > Satin> Crystal> Green Diamond. On the other hand, in waterlogging (T_2) Celera also contained the highest yield (4.19166 g) per plant and it was not much reduced amount like other verities yield per plant. Reduction of yield per plant is much in Satin, in water logging treatment it produce 2.591 g yield per plant. But the lowest yield founded in Crystal (1.02833 g)

followed by Green Diamond (1.2358 g). The varietal series by yield per plant in waterlogging treatment is Celera > Satin > Crystal > Green Diamond.

Table 10. Interaction effects of germplasm and treatments on yield per plant (g)

Germplasm × Treatment	**Yield per plant (g)**
Green Diamond × Control	3.808333 d
Crystal × Control	4.6 bc
Satin × Control	5.2 ab
Celera × Control	5.308333 a
Green Diamond × Waterlogging	1.235833 f
Crystal × Waterlogging	1.028333 f
Satin × Waterlogging	2.591667 e
Celera × Waterlogging	4.191667 cd
CV%	10.49
LSD$_{(0.05)}$	0.6420

CHAPTER V

SUMMARY, COCLUTION AND RECOMMENDATION

5.1 SUMMARY

Soil waterlogging is a majore abiotic stress which affect pulse production in Bangladesh. The experiment was conducted at Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka. To access the growth and yield performance of Mungbean in low laying or waterlogging area, this experiment comprised of four Mungbean germplasms (Green Diamond, Crystal, Satin, and Celera) and two treatments namely control and waterlogging were designated as T_1 and T_2. It was a pot experiment with an artificial waterlogging brick built chamber during the period from April, 2019 to July, 2019 to evaluate growth and yield was attributing character. The experiment was laid out in a two factorial experiment in factors Randomized Complete Block Design (RCBD) with three replications. Necessary intercultural operations were done as and when necessary. Significant variations and adaptability among stressed and non-stressed plants were observed in all germplasms. The data recorded from different characters were statistically analyzed to find out the significance difference of waterlogging at vegetative stage on growth and yield contributing characters of Mungbean.

Among the four germplasms maximum plant height was measured in Celera (28.08 cm) in waterlogging. Maximum number of leaves per plant was counted in Crystal (5) and Celera (5) at 38 days after showing, counted in Green diamond (4.666) in waterlogging stress. Maximum leaf length, leaf breadth, chlorophyll and content was recorded in control condition. The highest (12.333) number of pods per plant was obtained from control treatment. Maximum pod length (7.953 cm) measured from control. The highest number of seeds pod^{-1} (11) was recorded at control condition and the lowest (8.666) was recorded at waterlogging treatment. Similar results were found in case of total no of pod per plant. 100 seed weight (g) all were highest in control condition and lowest at waterlogging.

Celera produced the highest plant height in both control (37.040cm) and waterlogging (31.067 cm). Among the four germplasms Crystal produced highest (50.076) chlorophyll content than other germplasms. Celera produced highest no. of pod per plant (20), no. of seed per pod (11), 100 seed Weight (g), lowest moisture percentage and highest yield per plant (g) tolerating waterlogging condition. After waterlogging, new leaves initiated in the germplasm named Green Diamond in 39 DAS followed by Celera (40 DAS).

The interaction effect of waterlogging and germplasm was statistically significant in the maximum parameter. In waterlogging, tallest (31.067 cm) plant was observed in Celera and in control Celera contained maximum height (37.040 cm). No. of leaves was higher (11) in Green Diamond in control and it became 4.666 in waterlogging treatment. Celera produced higher pod per plant both in control (20) and waterlogging (12.333). In control treatment highest yield per plant contenting germplasm was Celera (5.3083 g) which was also highest (4.1916 g) in waterlogging treatment. In maximum cases Satin produced lower growth and yield and lower chlorophyll contenting germplasm.

5.2 CONCLUSION

Waterlogging stress is one of the most atrocious environmental factors restricting the productivity of Mungbean in tropical and subtropical region. Considering the findings of the present experiment following conclusions may be drawn-

- Plant height, leaf number, seed moisture percentage and chlorophyll content reduced significantly due to waterlogging. Highest plant height was found in Celera (37.067 cm) and shortest was in Satin (18.487 cm) at waterlogging condition.
- Yield reduced significantly in waterlogging condition. Maximum number of pods (12.333) per plant obtained from Celera and the minimum was in crystal (7.66) both at waterlogging. The highest 100-seed weight Celera (3.573 g) and the lowest in Crystal (2.276 g) at waterlogging
- Celera also contained lowest seed moisture percentage as a storage pulse crop after waterlogging stress. The Celera was more waterlogging stress tolerant than Green Diamond, Crystal and Satin.

Therefore, Celera can be added in the existing cropping pattern at waterlogging condition in flood-prone or low laying tropical and subtropical region.

5.3 RECOMMENDATION

The following recommendation were made for undertaking further research:

- Another experiment may be carried out with other Mungbean germplasm at different duration of waterlogging in different stage of Mungbean life cycle.

- Similar research work should be conducted by the researchers in wide range with germplasm of crops and different agro ecological zones (AEZ) of Bangladesh for regional amenability.

CHAPTAR VI

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APPENDICES

Appendix I. Characteristics of Soil of Experiment Pot

Morphological Characteristics of the Experimental Location

Morphological Features	Characteristics
Location	Sher-e Bangla Agricultural University Research Farm, Dhaka
AEZ	AEZ-28, Modhupur Tract
Soil Type	Sandy loam
Soil series	Tejgaon
Topography	Fairly leveled

The Initial Physical and Chemical Characteristics of Soil

Physical Characteristics	
Constituents	**Percent**
Sand	28
Sily	45
Clay	27
Textural class	Silty Clay
Chemical Characteristics	
Soil Characters	**Value**
pH	5.6
Organic Carbon %	0.48
Organic Matter %	0.76
Total Nitrogen%	0.03
Available P (ppm)	21.54
Exchangable K (me/100 g soil)	0.10

Appendix II. Monthly records of air temperature, relative humidity and rainfall during the period from April 2019 to July 2019

Month	Air temperature (^{0}C)		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	85	232

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

Appendix III. List of Necessary Tables for Result and Discussion.

Table 1. Interaction Effects on Varieties and Treatments in Mungbean

Treatments	Mean				
	No. of Seed per pod	**Sun Dry weight**	**Oven Dry Weight**	**Moisture %**	**Total weight**
V_1T_1	10 ^{ab}	3.973 ^{b}	3.596 ^{b}	35 ^{c}	15.233^{d}
V_2T_1	11 ^{a}	8.006 ^{a}	7.25 ^{a}	72 ^{a}	18.4 ^{bc}
V_3T_1	10 ^{b}	7.85 ^{a}	7.12 ^{a}	73.333^{a}	20.8 ^{ab}
V_4T_1	11 ^{ab}	3.71 ^{b}	3.366 ^{b}	33 ^{c}	21.233^{a}
V_1T_2	8.666 ^{c}	2.59 ^{cd}	2.25 ^{c}	28 ^{d}	4.943 ^{f}
V_2T_2	10 ^{b}	2.276 ^{d}	2.036 ^{c}	27.666^{d}	4.113 ^{f}
V_3T_2	8.666 ^{c}	2.993 ^{c}	2.533 ^{c}	47 ^{b}	10.366^{e}
V_4T_2	11 ^{a}	3.573 ^{b}	3.2 ^{b}	26 ^{d}	16.766^{cd}
CV%	4.15	7.17	4.80	3.68	10.49
LSD(0.05)	0.339	0.255	0.253	1.5786	1.197

Table 2. Effect of Waterlogging on Recovery to Normal Condition and new leaf Initiation in Mungbean Varieties

Treatments	Mean	
	Normal condition daf	**New leaf initiation**
V_1T_2	31.333^{c}	39.666^{c}
V_2T_2	36.666^{a}	43.333^{b}
V_3T_2	34.666^{b}	45.666^{a}
V_4T_2	31.666^{c}	40.333^{c}
CV%	1.92	1.42
LSD(0.05)	0.527	0.490

Appendix IV: Analysis of variance tables

Table 1. Analysis of variance on plant height

Source	DF	SS	MS	F	P
Replication	2	0.332	0.166		
Varitey	3	193.425	64.475**	89.37	0.0000
Treatment	1	324.135	324.135**	449.31	0.0000
Var*Treat	3	184.852	61.617**	85.41	0.0000
Error	14	10.100	0.721		
Total	23	712.843			

Table 2. Analysis of variance on leaf Number

Source	DF	SS	MS	F	P
Replication	2	0.083	0.042		
Germplasm	3	6.458	2.153**	7.70	0.0028
Treatment	1	108.375	108.375**	387.38	0.0000
Var*Treat	3	10.125	3.375**	12.06	0.0004
Error	14	3.917	0.280		
Total	23	128.958			

Table 3. Analysis of variance on leaf length

Source	DF	SS	MS	F	P
Rep	2	0.1222	0.0611		
Var	3	25.9744	8.6581**	75.44	0.0000
Treat	1	34.9451	34.9451**	304.47	0.0000
Var*Treat	3	26.7250	8.9083**	77.62	0.0000
Error	14	1.6068	0.1148		
Total	23	89.3735			

Table 4. Analysis of variance on chlorophyll content

Source	DF	SS	MS	F	P
Replication	2	3.36	1.681		
Varitey	3	414.82	138.274**	145.80	0.0000
Treatment	1	610.24	610.243**	643.45	0.0000
Var*Treat	3	156.60	52.199**	55.04	0.0000
Error	14	13.28	0.948		
Total	23	1198.30			

Table 5. Analysis of variance on pod number

Source	DF	SS	MS	F	P
Replication	2	1.333	0.667		
Germplasm	3	168.333	56.111**	73.65	0.0000
Treatment	1	130.667	130.667**	171.50	0.0000
Var*Treat	3	24.333	8.111**	10.65	0.0007
Error	14	10.667	0.762		
Total	23	335.333			

Table 6. Analysis of variance on pod length

Source	DF	SS	MS	F	P
Replication	2	0.1571	0.07854		
Germplasm	3	9.9684	3.32278**	49.11	0.0000
Treatment	1	0.9520	0.95202**	14.07	0.0021
Var*Treat	3	0.0428	0.01425^{NS}	0.21	0.8874
Error	14	0.9473	0.06766		
Total	23	12.0675			

Table 7. Analysis of variance on number of seeds per pod

Source	DF	SS	MS	F	P
Replication	2	0.2500	0.12500		
Varitey	3	11.0000	3.66667**	21.24	0.0000
Treatment	1	6.0000	6.00000**	34.76	0.0000
Var*Treat	3	4.3333	1.44444*	8.37	0.0020
Error	14	2.4167	0.17262		
Total	23	24.0000			

Table 8. Analysis of variance on oven dry weight

Source	DF	SS	MS	F	P
Rep	2	0.0011	0.0005		
Var	3	16.4637	5.4879**	56.97	0.0000
Treat	1	47.9968	47.9968**	498.26	0.0000
Var*Treat	3	27.0897	9.0299**	93.74	0.0000
Error	14	1.3486	0.0963		
Total	23	92.8998			

Table 9. Analysis of variance on moisture percentage

Source	DF	SS	MS	F	P
Replication	2	1.00	0.50		
Vareity	3	3933.83	1311.28**	350.79	0.0000
Treatment	1	2688.17	2688.17**	719.13	0.0000
Var*Treat	3	1447.17	482.39**	129.05	0.0000
Error	14	52.33	3.74		
Total	23	8122.50			

Table 10. Analysis of variance on 50% flowering

Source	DF	SS	MS	F	P
Replication	2	2.33	1.167		
Germplasm	3	157.12	52.375**	51.16	0.0000
Treatment	1	950.04	950.042**	927.95	0.0000
VAR*TREAT	3	2.13	0.708^{NS}	0.69	0.5720
Error	14	14.33	1.024		
Total	23	1125.96			

Table 11. Analysis of variance on yield per plant

Source	DF	SS	MS	F	P
Replication	2	0.9075	0.4538		
Treatment	1	36.5252	36.5252**	271.76	0.0000
Germplasm	3	18.8748	6.2916**	46.81	0.0000
TREAT*VAR	3	4.6122	1.5374**	11.44	0.0005
Error	14	1.8817	0.1344		
Total	23	62.8013			

Table 12. Analysis of variance on new leaf initiation days after waterlogging

Source	DF	SS	MS	F	P
Replicatio	2	0.5000	0.2500		
Germplasm	3	69.5833	23.1944**	64.23	0.0001
Error	6	2.1667	0.3611		
Total	11	72.2500			

Table 13. Analysis of variance on days for turning into normal condition

Source	DF	SS	MS	F	P
Replication	2	0.1667	0.0833		
Germplasm	3	58.2500	19.4167**	46.60	0.0002
Error	6	2.5000	0.416		
Total	11	60.9167			

Appendix V: Some Photographs of Experiment

Plate 1. Pictorial View of experimental site

Plate 2. Artificial Waterlogging Condition

Plate 3. Recovered plant from germplasm Celera

Plate 4. Recovered plant from variety Crystal

Plate 5. Flowering and Fruiting of germplasm Celera after 72 hours waterlogging tolerance

Plate 6. Wilting of mungbean plant after 72 hours waterlogging

Plate 7. Plants of germplasm Celera after waterlogging