RESPONSE OF SESAME GENOTYPES TO WATERLOGGING STRESS

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This is to certify that thesis entitled "**RESPONSE OF SESAME GENOTYPES TO WATERLOGGING STRESS"** submitted to the faculty of agriculture, Sher-e-Bangla Agricultural University, Dhaka-1207, in partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** in AGRICULTURALBOTANY embodies the result of a piece of *bona fide* research work carried out by **MOHAMMAD HABIBULLAH**, Registration No.13-05801under my supervision and 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 the investigation has been duly acknowledged by him.

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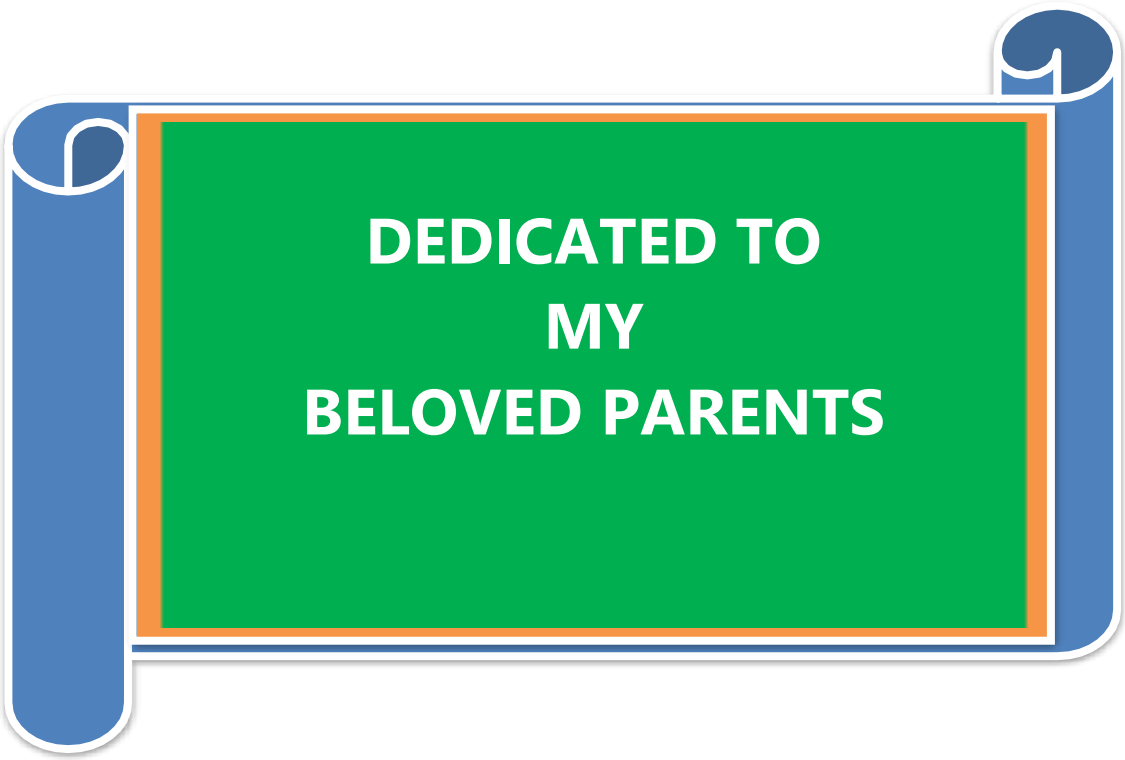
DEDICATED TO
MY
BELOVED PARENTS

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RESPONSE OF SESAME GENOTYPES TO WATERLOGGING STRESS

ABSTRACT

Sesame is sensitive to waterlogging, and its growth is devastatingly impacted under excess moisture conditions. Thus, waterlogging tolerance is crucial to alleviate yield constraints, particularly under expected climate change. Three individual experiments were conducted at Bangladesh Agricultural Research Institute (BARI) farm and Physiology Laboratory Joydebpur, Gazipur, during the period of 25 January 2016 to 09 October 2018 to study the responses of sesame genotypes to waterlogging stress. The first experiment was conducted in the plant Physiology Laboratory of BARI during 27 January 2016 to 18 February 2016 to screen the sesame genotypes at seedling stage under waterlogging condition. In this study, 119 diverse sesame genotypes were screened for their tolerance to 12, 24, 48, and 72 h of waterlogging relative to non-waterlogged conditions. All plants died under 72 h of waterlogging, while 13.45%, 31.93%, and 45.38% of genotypes survived at 48, 24, and 12 h, respectively. Based on the seedling parameters and waterlogging tolerance coefficients, genotypes BD-7008 and BD-6985 exhibited the highest tolerance to waterlogging, while BD-6996 and JP-01811 were the most sensitive ones. The responses of these four genotypes to waterlogged conditions were assessed at different plant growth stages—30, 40, and 50 days after sowing (DAS) versus normal conditions. Waterlogging, particularly when it occurred within 30 DAS, destructively affected the physiological and morphological characteristics, which was reflected in the growth and yield attributes. Genotype BD-7008, followed by BD-6985, exhibited the highest chlorophyll and proline contents as well as enzymatic antioxidant activities, including superoxide dismutase (SOD), peroxidase (POD), and catalase (CAT). These anatomical, biochemical and physiological adjustments ameliorated the adverse effects of waterlogging, resulting in higher yields for both genotypes. Conversely, JP-01811 presented the lowest chlorophyll and proline contents as well as enzymatic antioxidant activities, resulting in the poorest growth and seed yield.

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

ABBREVIATIONS AND ACRONYMS

Full word	Abbreviation
Agro-ecological zones	AEZ
Analysis of Variance	ANOVA
And others	*et al.*
Days after Sowing	DAS
Figure	Fig.
Full Length	FL
Full Weight	FW
Gram	g
Kilogram	Kg
Least Significant Difference	LSD
Metric ton	MT
Namely	Viz.
Percentage	%
Randomized Complete Block Design	RCBD
Relative Humidity	RH
Root Length	RL
Shoot Length	SL
Species (plural number)	spp.
Temperature	Temp°C
Ton per Hectare	t/ha
That is	i.e.
Variety	var.
Waterlogging Tolerance Coefficient	WTC
Superoxide Dismutase	SOD
Peroxidase	POD
Catalase	CAT
Relative Water Content	RWC
Adenosine Triphosphate	ATP
Alcohol Dehydrogenase	ADH
Lactate Dehydrogenase	LDH

Chapter I
INTRODUCTION

Sesame (*Sesamum indicum* L.) is a belongs to the family Pedaliaceae and knownas "Queen of oil seed crops" by virtue of its excellent quality. The exact natural origin of the species is unknown, although numerous wild relatives occur in Africa and a smaller number in India. It is widely adapted in tropical regions around the world and cultivated for its edible seeds. Most of the sesame seeds are practiced for oil extraction and the rest are used for edible and religious purposes. It is an annual plant growing up to 50 to 100 cm tall, occasionally perennial crop which needs a growing period of 70 to 150 days with opposite leaves 4 to 14 cm long with an entire margin; they are broad lanceolate. The flowers are white to purple, tubular, 3 to 5 cm long, with a four-lobed mouth. Sesame, which has an extensively branched feeder root systems, appears to improve soil structure. It has capacity to cope drought environment but not to excess water wet condition.

About 70% of the World's sesame seed is refined into oil and meal. Total annual consumption is about 65% for oil extraction and 35% for food. (Pusadkar *et al.,* 2015). The sesame oil has been traditionally utilized for cooking and as a flavor additive in food products of Asian and Western countries (Pasterello et, ai, 2001). It is also reported that this oil employed for both dilatory and therapeutics applications. The seeds of sesame are reported as the seeds of immortality perhaps for its resistance to oxidation and rancidity even stored in ambident air temperature (Bedigian and Harlan, 1986). Seeds may be eaten whole either raw and roasted, salted or mixed with lemon and honey but are often ground in to pest which may be sweetened with sugar. Sesame seeds which are sources of Phyto-nutrients such as omega-6 fatty acids, flavonoids, phenolic anti-oxidants, vitamins and dietary fiber are also used in traditional medicines for their nutritive, preventive, curative, and potent anti-cancerous and health promoting properties. African people have practiced sesame to prepare perfumes and cologne that has been made from sesame flowers. Sesame seed consumption appears to increase plasma gamma-tocopherol and enhanced vitamin-E activity which are believed to prevent cancer and heart disease (Cooney *et al.,* 2001).

Sesame seeds is utilized on bread, buns, cookies, snacks, and as an alternative to breakfast cereal mixed.

The chemical composition of sesame seed reveals that it is an important source of oil (44-58%), protein (18-25%), carbohydrate (~13.5%) and ash (~5%) (Borchani *et al*., 2010). In addition, it contains greater than 80% of its oil is in the major mode of unsaturated fatty acids, in particular, it's rich in omega-6 fatty acids which are a type of polyunsaturated fat that is essential to your diet and plays an important role in heart disease prevention which are more valuable for human health than are saturated fatty acids. They provide as a good source of copper, manganese and calcium which are effective in reducing pain, osteoporosis and reduction of swelling during rheumatoid arthritis (Chakraborthy *et al*., 2008). Sesamin has bactericidal and insecticidal activities and it also acts as an antioxidant which can impede the absorption of cholesterol and the production of cholesterol in the liver. It is used as a synergist of pyrethrum insecticides (Simon *et al.,* 1984). The oil of sesame is also used in paints, soaps, cosmetics, perfumes. Sesame flowers are functional in treatment of cancer, alopecia, and constipation, roots are having antifungal activity and leaves are used in infant cholera, diarrhea, dysentery and urinary infections (Pusadkar *et al.,* 2015). Sesame oil is a pharmaceutics aid utilized as a solvent for intramuscular injections and has nutritive, demulcent and emollient properties (Tyler *et al.,* 1976) and it is work as a laxative. It is also operated as an antibacterial mouthwash.

It is one of the most significant and ancient oilseeds crop in many parts of world. It has beendescribed that world sesame acreage 11.2 million hectors with 6.9 million MT total production where India is the first globally as sesame producing country. The 0.8 million MT, 0.6 million MT, 0.4 million MT, 0.5 million MT and 0.2 million MT sesame manufactured in India, China, Nigeria, Myanmar and Ethiopia, respectively (FAO, 2011). The white and light-colored sesame seeds are produced commonly in West Asia, Indian sub-continent, America, and Europe. In China and Southeast Asia, darker-colored sesame seeds are mainly found. In 2010, more than a billion-dollar worth of trade of sesame seeds was reported. The largest sesame importer in the world is Japan since sesame oil is an essential ingredient in Japanese cooking (APEDA). In addition, China is the world's second largest sesame importer and the US, Canada, the Netherlands, France, and Turkey are other major sesame importing countries.

Usually, sesame is the crop of dry and hot climate. Tolerable temperature is 25-30^0 C. Below20^0 C, germination is delay and hampered. Temperature of less than is 18^0 C after emergence, severely retards growth (Bennett 2003). Sesame is cultivated to many soil typesbut it thrives best on well-grained fertile soils of neutral pH (Opliner1997) The total amount of water required to produce sesame ranges from 600-1000mm and can be met from available soil moisture at sowing, rainfall during the growing season and irrigation (Bennett, 2003). It is manually cultivated by small marginal farmers under rain-fed condition.

Sesame is the second largest origin of edible oil crop Bangladesh next to *Brassica* both in respect of acreage and production. More precisely, the area under sesame cultivation was 90.82 thousand hectares in 1989, whereas it decreased to 34.12 thousand hectares in 2015 (BBS, 2015). In Bangladesh total production is 2970 MT, Barishal division is higher in sesame production 944 hectors with 863 MT. Beside this Faridpur, Rangpur, Gaibandha, Khagrachori are sesame growing area (BBS, 2015). The average yield level of sesame (500-600 kg ha^{-1}) in Bangladesh is quite little compare to other countries such as China, Ethiopia and India (FAO, 2011). The acreage and production of sesame are decreasing gradually. Therefore, it is necessary to increase the seed yield of sesame in comparison to other countries by using suitable varieties, innovative agricultural technologies with changing climate. This low yield may be attributed to several reasons, but waterlogging is a primary factor that has a severe effect in sesame production. Because, sesame is mainly grown in *kharif*- I season in Bangladesh, which is the dry wet transition period due to the start of monsoon and often it is affected by waterlogging condition. Seasonal rainfall often causes waterlogging damage to the sesame production in Bangladesh. The causes of production reduction due to reduction of cultivation area decreasing available land, less considering as cereal crops, lack of suitable genotype, inefficient of management of sesame under adverse condition. Sesame is cultivated to many soil types, but it thrives best on well-drained, fertile soils of neutral P^H (Oplinger, 1990). Usually, sesame is the crop of dry and hot climate. Tolerable temperature is 25°C-30°C. Bellow 20°C germination is delay and hampered. There are several abiotic stresses like salinity, drought, water logged condition are major problem for sesame cultivation. Among them water logged condition is one of the leading problems for sesame production. Sesame is seriously sensitive to water logging

such that even short periods of water logging will result in significant reduction in plant numbers and seed yield (Bennett, 2003). Bennett (2003) also described that the ideal temperature for growth varies with cultivar in the range of 27°C-35°C. A temperature of less than 18°C after emergence severely retards growth (Bennett, 2003). The total amount of water required to produce sesame ranges from 600-1000mm and can be met from available soil moisture at sowing, rainfall during the growing season and irrigation (Bennett, 2003). The situation may become poor due to climate change which may enhance the frequency and severity of the abiotic stress. In waterlogged soils, compounds like carbon dioxide, ethylene, manganese and iron may accrue in concentrations which are potentially toxic to plants. Sesame is very precise to excess moisture and crop losses due to waterlogging are considerably high. It is mainly cultivated by small and marginal farmers under rainfed condition. Developing resistant varieties is the most ideal and economic approach to manage the stress as agronomic measures and engineering structures are costly and have their own limitations.

Waterlogging is considered as the major abiotic stress in many parts of the world. Among the abiotic stresses, Waterlogging leads to a series of morphological, physiological, biochemical and anatomical changes (Cortezi and Colli, 2011; Alves *et al*., 2012). Consequently, plant growth, development and production are negatively affected (Jackson and Colmer, 2005). Waterlogging happens when the water table attains a level at which the soil pores in the root zone of the plants are fully saturated and restricts normal air circulation. Consequently, oxygen levels in the soil decline and carbon dioxide concentration increase, which adversely affects the growth and development of plant roots (Vartapetian and Jackson, 1997). Saha *et al*, 2016 reported that overall plant growth, including plant height, root volume, root length, leaf area and root dry weight per plant sesame genotypes significantly decreased because of waterlogging. Decline in O_2 availability results in a reduction in the energy produced by the plant, because of the shift from aerobic to anaerobic respiration, which is less efficient in terms of ATP synthesis. A limited reduction in O_2 (hypoxia) results in a reorganization of metabolic fluxes, so that energy usage is optimized to fulfill the house-keeping activities of the cell which are required to prevent disorganization and death. The complete absence of O_2 (anoxia) is considerably more problematic for cell, which under such conditions can only rely on

glycolysis for ATP production, thus rapidly entering into an energy crisis. The formation of adventitious roots, aerenchyma and hypertrophied lenticels, are the most common morphological and anatomical ("morpho-anatomical") responses of plants to roothypoxia. All these waterlogging adaptions facilitate oxygen capture of submerged tissues, and they also encourage rhizosphere oxidation and the removal of toxic products. The extensive network of air spaces in aerenchyma tissue helps for the storage and exchange of gases within the plant and maintains a hypoxia tolerance pathway.

Due to the nonuniform, indeterminate nature of the bloom period, the reproductive, ripening, and drying phases of the seed tend to overlap. Seed lowest on the plant will mature first, even as the upper part of the plant is still flowering or has just formed seed capsules. Unfortunately, the major obstacle to sesame expansion is low seed yield which results due to lack of non-shattering, waterlogged, and disease & insect resistant variety. Sesame requires adequate moisture for germination and primary growth. While the crop survives drought, as well as presence of excessive water, the yields are significantly lower in either condition. Moisture levels before planting and flowering effect yield most. Most commercial cultivars of sesame are intolerant of waterlogging. Rainfall late in the season prolongs growth and increases loss to dehiscence, when the seedpod shatters, scattering the seed. Wind can also cause shattering at harvest and lodging the plants.

Short-term waterlogging often firstly causes oxygen deficiency (hypoxia or anoxia) in plants and leads to roots damage and leaf wilting and chlorosis under transient or sustained flooding conditions (Meyer *et al*., 1987; Grassini *et al*. 2007). And long-term waterlogging can cause crop yield losses up to 30% when it occurs early in the season (IPCC 2007). Waterlogging causes a shortfall in oxygen availability to plants, which is felt directly by the root system, and indirectly by the shoots. During waterlogging environment, oxidative stress occurs in the plant cell due to decreased stomatal conductivity which restricts CO_2 influx into the leaves which leads to increase the formation of reactive oxygen species (ROS) such as singlet oxygen ($^1O_2$), superoxide radical ($O_2^{\bullet -}$), hydrogen peroxide (H_2O_2), and hydroxyl radical ($^{\bullet}OH$) by enhanced leakage of electrons to molecular oxygen in different parts of the plant cell and also produced highly cytotoxic and reactive properties MG and MDA. These all substance are highly toxic to plants cell because they can damage various cellular mechanisms, such as lipid per-oxidation, protein degradation, inactivationof enzymes, damage of Nucleic acids, disrupt in cells normal metabolism and

damage of cell membrane which leads to cell death (Preira *et al*., 2010).

Plants have a battery of enzymatic and non-enzymatic scavenging pathways or detoxification systems which function as an extremely efficient cooperative system to counter the deleterious effects of ROS and preserve the appropriate level of ROS for growth and message transfer pathways (Apel and Hirt, 2004 and Mittler *et al*., 2004). A number of studies have shown that the capability of scavenging ROS and reducing their damaging effects often correlates with waterlogging tolerance of plants (Sairam *et al*., 2008). Numerous research findings supported the notion that coordinated induction and regulation of the antioxidant and glyoxalase pathway enzymes is necessary for obtaining substantial tolerance against oxidative stress.

The dissolution of protoplasm and cell wall during lysigenous aerenchyma formation involves activities of various enzymes especially those involves in cell wall loosening and related enzymes like cellulose etc. A homolog of XET was reported in maize during flooding –induced aerenchyma development (Saab and Sachs, 1996) concluded that XET is a novel waterlogging tolerance gene related to structural adaption, and can be induced in roots of sesame and wheat under anoxia stress.

The principal component analysis identified the traits that contributed most to the divergence and the genotypes were. However, the stress tolerant mechanism is not fully understood. Therefore, the better understanding of the underlying tolerant mechanism is very important to develop waterlogging tolerant sesame. In view of the above circumstances, the present study was guided by the following objectives.

Objectives of the Study

1. To investigate the effects of waterlogging on different sesame genotypes at seedling stage under laboratory condition.
2. To investigate the adverse effects of waterlogging on morphological, yield contribute characters and yield of different sesame genotypes and
3. To find out the physiological mechanism of water logging tolerance in sesame.

Chapter II

REVIEW OF LITERATURE

Land plants, including most of the crops, are aerobic organisms depending on a steady supply of oxygen from aerial or underground tissues (B.B. Vartapetian and M.B. Jackson, 1997). Waterlogging, which arises from the excess soil water and causes severe constraint on crop growth and productivity, has currently become a major abiotic stress in large areas of the world (M.B. Jackson and T.D. Colmer, 2005; P.K. Aggarwal *et al*., 2006). Short-term waterlogging often firstly causes oxygen deficiency (hypoxia or anoxia) in plants and leads to roots damage and leaf wilting and chlorosis under transient or sustained flooding conditions (W.S. Meyer *et al*., 1987; E. Maltby, 1991; P. Grassini *et al*., 2007). And long-term waterlogging can cause crop yield losses up to 30% when it occurs early in the season (IPCC, Climate Change 2007). Waterlogging causes a shortfall in oxygen availability to plants, which is felt directly by the root system, and indirectly by the shoots (S.J. Capon *et al*., 2009). In tissues suffering hypoxia (and especially anoxia), oxygen dependent processes are suppressed, both carbon assimilation and photosynthate utilization are inhibited, and the functional relationships (especially the internal transport of oxygen) between roots andshoots are disturbed (M. Irfan *et al*., 2010; V. Chugh *et al*., 2012).

The response of a plant to hypoxia can be conceptually divided into three stages. Initially, the plant rapidly induces a set of signal transduction components, which then activates the second stage, a metabolic adaptation involving fermentation pathways. Finally, the third stage involves morphological changes such as the formation of gas filled air spaces (aerenchyma) and/or adventitious root, depending on the tolerance of the plant (S.H.F.W. Justin and W. Armstrong 1987; D.E. Evans, 2003). Generally, Plant adaptations to waterlogging or oxygen deprivation in the soil include avoidance strategies at the morphological level (e.g., lenticels and aerenchyma, pneumatophores) and plasmatic tolerance mechanisms at the physiological level. Some plants respond to hypoxia by generating metabolic energy from fermentative glycolysis rather than from oxidative respiration (T. Fukao and J. Bailey-Serres, 2004; D. Kumutha *et al.*, 2008; A.M. Ismail *et al*., 2009). When the respiration shifts from the aerobic to the anaerobic mode, the

anaerobic proteins (ANPs), such as pyruvate decarboxylase (PDC), alcohol dehydrogenase (ADH) and lactate dehydrogenase (LDH) play a pivot role. PDC catalyzes the irreversible conversion of pyruvate to acetaldehyde, and ADH converts the acetaldehyde to ethanol and regenerates NAD+, a process which is critical for sustaining glycolysis under hypoxia (K.P. Ismond *et al*., 2003). LDH also produces NAD+ but from pyruvate's conversion to lactate. The de novo synthesis of PDC, LDH and ADH has been documented for a number of plant species (K.P. Ismond *et al*., 2003; B.R. Maricle *et al*., 2006; H. Kato-Noguchi and M. Morokuma, 2007; D. Vodnika *et al*., 2009). The accumulation of alcohol is less toxic than that of lactic acid, and thus the period of the shift from alcoholic to lactic fermentation is considered as an important indicator for the ability of a plant to survive hypoxia without suffering severe cellular damage (A. Mustroph *et al*., 2006).

It has been observed that root hypoxia causes photooxidative damage to leaves via an increased generation of reactive oxygen species (ROS), such as superoxide (O_2 −), hydrogen peroxide (H_2O_2) and the hydroxyl radical (OH•), which readily attack leaf chloroplasts and lead to leaf chlorosis and senescence (R.Y. Yordanova *et al*., 2003; R.Y. Yordanova *et al*., 2004). The ROS scavenging is carried out by a number of well-characterized enzymes, primarily superoxide dismutase (SOD), ascorbate peroxide (APX) and catalase (CAT). The latter two are responsible for the regulation of intracellular H_2O_2 levels (I.M. Moller *et al*., 2007). It has been identified that high levels of SOD, CAT and APX are critical for the survival of rice (T. Ushimaro *et al*., 1992), tobacco (] W.P. Hurng and C.H. Kao, 1994; W.P. Hurng and C.H. Kao, 1994), sweet potato (S.Y. Hwang *et al*., 2000), mungbean (S. Ahmed *et al*., 2002), Sunflower (P. Grassini *et al*., 2007), and wheat (C. Li *et al*., 2011) under waterlogging conditions.

The molecule malondialdehyde (MDA) has been qualified with lipid peroxidation via an increased generation of ROS, and thus its quantification has been suggested as a general indicator for waterlogging tolerance (F.B. Wu *et al*., 2003; D. Kumutha *et al*., 2009). The formation of adventitious roots, aerenchyma and hypertrophied lenticels, are the most common morphological and anatomical ("morpho-anatomical") responses of plants to root hypoxia (A.I. Malik *et al*., 2003). All of these waterlogging adaptions facilitate oxygen

capture of submerged tissues (A.I. Malik *et al*., 2003; T.D. Colmer, 2003), and they also encourage rhizosphere oxidation and the removal of toxic products (E.J.W. Visser *et al*., 2000; H.A. Kratsch and W. Graves, 2005). The extensive network of air spaces in aerenchyma tissue helps for the storage and exchange of gases within the plant and maintains a hypoxia tolerance pathway (J.Y. Pang *et al*., 2006). It is recognized there exists two types of aerenchyma-schizogenous and lysigenous in plants by Jackson and Armstrong (M.B. Jackson, and W. Armstrong, 1999). Schizogenous aerenchyma generates species-specific patterns of cell arrangements and forms constitutively in roots of wetland species without cell death, while the latter is generated following programmed cell death and cell wall autolysis as a response to abiotic stress (A. Gunawardena *et al*., 2001).

2.2.1. Waterlogging affects numerous physiological and metabolic processes

Waterlogging affects numerous physiological and metabolic processes (E.J.W. Visser and R. Pieril, 2007; S.M. Rich *et al*., 2008; K.K. D *et al*., 2009) One of the primary pathways to be induced is glycolytic fermentation, as repeatedly observed in the form of increases in alcohol fermentation catalyzed by PDC and ADH (T. Yamanoshita *et al*., 2005; R.H. Su and C.H. Lin, 1996; O. De Simone *et al*., 2002). Induction of lactate fermentation (catalyzed by LDH) has been documented in some flooding-tolerant plants within a few hours of the onset of hypoxia (J. Rivoal and A.D. Hanson, 1994; Z.X. Zhang *et al*., 2006). Although ZZM2541 roots responded during waterlogging by an increase in PDC and ADH activity, LDH activity was not largely induced. This suggests that a main pathway of NAD+ regeneration in waterlogged ZZM2541 is not lactate fermentation but alcohol fermentation. Therefore, activation of ethanolic fermentation was considered to be one of the strategies for ZZM2541 to survive anaerobiosis, which is in accordance with the findings in waterlogged seedlings of cucumber (Y.Y. Kang *et al*., 2009) and chrysanthemum. The decrease in both PDC and ADH activities following a 4 or 6 days' of increase during the early waterlogging stage may be due to the oxygen available to roots through aerenchyma in ZZM2541. Ezhi-2 roots rely on lactate fermentation after only a relatively short period of hypoxia, a characteristic feature of hypoxia-sensitive plants (K. Nada *et al*., 2004), which is agreement with the findings in the waterlogging susceptible chrysanthemum cultivar. However, in Arabidopsis thaliana, PDC has been shown to be the

controlling step in ethanol fermentation. In the present study, a significant induction of PDC at day 2 in waterlogged Ezhi-2 inferred that alcohol fermentation still operated in this waterlogging susceptible accession. Nevertheless, a drastic decrease in PDC after day 4 inferred that alcohol fermentation is not the main pathway responsible for the elimination of prolonged hypoxia stress. The physiology of the shoots can be expected to be disturbed by the absence of an energy source in the roots. Oxidative stress in the stressed plant results from a shortfall in ROS scavenging, either due to an overload of ROS and/or to a decrease in the activity of the scavenging enzymes (J.C. Yiu *et al*., 2009). The tolerant accessions ZZM2541 sustained higher levels of SOD, APX and CAT than Ezhi-2, which allowed it to maintain a better balance between ROS formation and detoxification. APX and CAT activity accumulated rapidly in the early stages of stress (day 2) and maintained a higher level during the later stages of waterlogging in the tolerant ZZM2541, which inferred that H_2O_2 scavenging by APX and CAT is one of the most important ways for the present tolerant sesame accession against waterlogged stress. These findings are consistent with previous reports such as in tomato and eggplant (K.H.R. Lin *et al*., 2004). It is notable that SOD increased sharply in ZZM2541 after 2 days of waterlogging and sustained a high level until day 6, whereas CAT turned to decrease and APX sustained increasing in a gentle rate. It is suggested that there are other mechanisms involved in scavenging H_2O_2 besides APX and CAT during the late stages of waterlogging. Higher levels of ROS are characterized to increase lipid peroxidation, allowing MDA levels to be considered as an indicator of lipid peroxidation under stress. The MDA content of Ezhi-2 was greater than that of ZZM2541, implying a lesser ability to remove ROS by enhancing SOD, APX and CAT activity. A similar phenomenon was also observed in the waterlogging susceptible chrysanthemum cultivar (D.M. Yin *et al*., 2009).

Reactive oxygen species (ROS) are generated not only in mitochondria during electron transport and oxidative phosphorylation but also in plasma membranes by NADPH oxide (NOX). Excess amounts of ROS damage high molecular weight molecules such as DNA, protein and lipid, resulting in cellular dysfunction and apoptosis. At lower levels, however, ROS play an important role as signaling molecules in diverse physiological processes. Enhancement of the antioxidant capacity by pharmacological or nutritional intervention

could reduce oxidative stress and ameliorate oxidative stress-related diseases. The capacity can be increased by induction of phase II antioxidant enzymes as well as superoxide dismutase (SOD) and catalase. Modification of the cysteine sulfhydryl groups of Keap1 by ROS and electrophiles changes its conformation, resulting in Nrf2 release and translocation into the nucleus. Here, we observed if SC-1 could generate ROS. The intracellular ROS level was increased 0.5 h after treatment with SC-1, which remained elevated at 1 h and then gradually decreased to the basal level at 6 h. Pretreatment for 1 h with N-acetylcysteine (NAC) at 2.5 mM, which elevates intracellular glutathione levels, eliminated HO-1 induction by SC-1 at 24 h after treatment, suggesting that transient ROS production is involved in Nrf2/ARE activation by SC-1. Furthermore, whether ROS that were generated transiently by SC-1 participated in activation of p38. NAC treatment abolished SC-1-induced phosphorylation of p38, indicating that ROS are upstream signals of p38 in Nrf2/ARE activation by SC-1.

Since various compounds have been shown to protect against cell death by enhancing the antioxidant capacity via Nrf2/ARE activation, we tested if SC-1 could ameliorate oxidative stress-induced neuronal cell death. We pretreated PC12 cells with SC-1 for 6 h prior to treatment with different concentrations of H_2O_2. SC-1 significantly attenuated H_2 H_2O_2 O_2- induced cell death in a dose-dependent manner. For instance, pretreatment with SC-1 (2, 5, 10 lM) increased cell viability after treatment with 75 lM of H_2O_2 from 40% to 52%, 67% and 82%, respectively. These results show that preconditioning by SC-1 protects against oxidative stress-induced PC12 cell death.
(H. Nanako *et al*., 2011).

2.2.2. Morphological Adaptations

Plants show a range of morphological adaptations at their different growth stages under flooding stress condition. Rice seeds are able to germinate anaerobically. After germination, the coleoptile of rice seedlings rapidly elongate to avoid the anaerobic condition derived from waterlogged condition (Magneschi and Perata 2009). Adventitious root formation is one of the major adaptation responses under flooding stress. Tolerant plant varieties are characterized with higher generation of adventitious root, compared to

susceptible plant varieties. Susceptible chrysanthemum cultivar (13-13) showed wilting and leaf chlorosis symptoms (at 4 days of waterlogging) with small number of adventitious root (at 20 days of waterlogging stress). In contrast, tolerant chrysanthemum cultivar (53-4) produced vigorous adventitious roots and showed less damage effects on leaves (Yin *et al*. 2009). *Sesbania javanica* has special features in stem (hypertrophy) and adventitious root formation which contributed to *S. javanica's* tolerance to flooding (Jackson 2006). The formation of ethylene and adventitious root formation were documented in waterlogged tomato, Rumex spp., and Lepidium latifolium (Wang and Arteca 1992; Banga *et al*. 1997; Chen *et al*. 2002). *Zea mays* plants exposed to waterlogging showed reduction of seminal root diameter (Grzesiak *et al*, 1999). Root hairs in *Paspalum dilatatum* was found to be decreased upon waterlogging (Vasellati *et al*. 2001). Rapid elongations of submerged shoots and leaf are observed in flood-affected plants which bring plants to contact with air to mitigate oxygen deficiency (Jackson 2008). Stem elongation is a commonly occurred adaptation mechanism in submerged rice cultivars (Kende *et al*. 1998), whereas rapid growth of petioles and leaf blade has been demonstrated in Rumex palustris (Voesenek *et al*, 2003). Aquatic leaves are often filamentous, dissected leaves with reduced number of stomata (Sculthorpe 1967). In general, amphibious plants possess elongated and thinner leaves with higher specific leaf areas when grown under aquatic condition to provide sufficient gas exchange area (Mommer *et al*, 2004)

2.2.3. Morpho physiological changes

Reduction of growth rate is one of the primary effects of waterlogging. Waterlogging condition dramatically affects plant growth, development, and survival in various ways (Parent *et al*. 2008). Height and diameter of plant, number of leaves, and total growing period of maize plant were harshly affected by waterlogging (2 cm standing water) (Ali *et al*. 1999). In their study, Mauchamp *et al*. (2001) showed that partial submergence (50 and 80%) considerably improved accumulation of biomass and growth, while full submergence reduced the values of same parameters in Phragmites australis plant. Later on, Mensah *et al*. (2006) showed flooding reduced dry matter accumulation and number of leaves per plant in sesame. Long-term flooding induced chlorosis, abortion of flower, and reduced time of maturity.

The overall growth of sesame plant was negatively affected by continuous flooding. Gonzalez *et al*. (2009) carried an experiment with Quinoa (*Chenopodium quinoa Wild*.) plants and found specific leaf area, and leaf areas were reduced under waterlogging stress by 26% and 36%, respectively, in contrast to control. Lone and Warsi (2009) demonstrated that plant height and ear height of maize were severely affected under flooding. Almost all tested genotypes showed reduction in plant height due to flooding. Ezin *et al*. (2010) observed differential growth responses in two contrasting varieties of cultivated and wild origin. Plant height, leaf length, and leaf number were decreased, but formation of adventitious root was increased with increased duration of waterlogging in all cultivars. Among the tested tomato genotypes, LA1579 showed sensitiveness to flood. The CLN2498E and CA4 genotypes exhibited high tolerance to flooding stress which is followed by LA1421 genotype. Paltaa *et al*. (2010) also observed that the leaf area of Cicer arietinum reduced by 56–70% compared to well drain and depending on the cultivars. Compared to desi cultivar (Rupali), the growth retardation was less in kabuli cultivar (Almaz). Dry weight of shoot under waterlogging condition reduced by 70 and 56% in the cultivars Rupali and Almaz, respectively.

The number of branches decreased by 50% in both chickpea cultivars under waterlogging stress. Similar alteration of root growth and activity was also observed under extended waterlogging. Prasanna and Rao (2014) conducted an experiment with green gram and reported significant difference on growth parameters due to waterlogging. Plant height, leaf area, number of leaves, and total dry matter were significantly affected by waterlogging throughout the life cycle. The effect of 4-d waterlogging was more severe in comparison with 2-d waterlogging treatment over the control. In waterlogged plants, plant height, number of branches, number of leaves, leaf area, and total dry matter were reduced by 30–34% compared to well-watered condition. Ren *et al*. (2014) performed a study in a field to elucidate the responses of waterlogging for different growth and reproductive stage of summer maize and observed that waterlogging negatively affected the overall growth and development of crop.

Sesame *(Sesamum indicum* L.), otherwise known as sesamum or benniseed, member of the family Pedaliaceae, is one of the most ancient oilseeds crop known to mankind. It is known under several names in different countries *viz:* simsim, benniseed, til, gingelly and a jonjoli (Khidir, 1997). Sesame seed contains 38-54% oil and 18-25% protein. Because of its high oil quality and a wide use in raw foods, confectioneries and bakery industries, the demand of sesame seed is increasing significantly in the global market (Ashri, 1989). Sesame oil is a good source of vegetable oil since it has antioxidants such as sesamin, sesamol and sesamolin and ideal fatty acid composition. The antioxidants make the oil very stable and it has therefore a long shelf life (Suja, 2004).

Sesame is a poor man's crop normally cultivated under rainfed condition and is very sensitive to excess moisture (Khidir, 1997). Bennet (1995) already reported that good drainage is important for sesame as it is very susceptible to short duration of waterlogging. Climate change is causing increased periodic flood throughout the world resulting in severe crop reduction (Olesen *et al.*, 2011). Development of flood tolerant cultivar is the way to overcome this problem (Hussain *et al*., 2014). Setter and Waters (2003) defined waterlogging tolerance as the maintenance of high yields under water logged compared to non-waterlogged conditions. Tolerance to waterlogging varies with species. A study conducted by Al Ani *et al*. (1985) revealed that seeds with carbohydrate reserves such as rice and wheat were generally more tolerant to hypoxia (low oxygen) or even anoxia (absence of oxygen) than seeds with fatty acid reserves such as sunflower, cotton and sesame.

Among different oil seed crops, sesame was the most susceptible one to water logged and acidic soil condition (Ashri, 1997). Poor soil aeration associated with excessive moisture was affecting plant growth in a negative way (Boru *et al*., 2011). De Simone *et al*. (2002) reported that in most plant species, flooding induced hypoxic and anoxic conditions in soil reducing the capability of roots to supply nutrients and water for plant growth and development and this led to the reduction of crop yield.

The degree of stress on sesame in waterlogging soils depends on the crop stage, duration of flooding, soil type, growth conditions and genotypes. When two sesame varieties, BARI Til 2 and BARI Til 3 were studied, varietal difference was seen with respect to the effect of waterlogging and its duration. Yield was rapidly decreased as duration increased. The varieties recorded a maximum yield loss of 51.67% and 58.24% respectively for a continuous period of 36 hours of waterlogging at two crop (vegetative and flowering) stages (Sarkar *et al.,* 2016).

Seedling test conducted in controlled conditions is the common method to screen for waterlogging tolerance (Zhou *et al.,* 2010). Hussain *et al*. (2014) screened sixty accessions of cotton (*Gossypium hirsutum* L.) at three different growth stages viz. seedling, flowering and boll formation stages and was found that seedling stage was the most sensitive growth stage and selection at the seedling stage can enhance tolerance to flooding stress.

According to Parelle *et al*. (2010), genetic variability for waterlogging tolerance can be assessed indirectly as survival percentage, crop damage indices and negative influence on growth and yield. Waterlogging reduced plant height, number of primary branches plant^{-1}, number of capsules plant^{-1}, 1000 seed weight and seed yield significantly in sesame (Shajahan, 2016). Martin *et al*. (2006) and Hussain *et al*. (2014) reported that plant responses to flooding stress in terms of survival percentage is a vital factor to assess the degree of flooding tolerance. Variability in this trait is directly related with genetic variability for flooding tolerance (Parelle *et al*., 2010). In rapeseed, waterlogging at the seedling stage showed a large diversity in survival ability and it was significantly correlated with the yield index (Zhou, 2014).

Plant height and leaf area in castor bean *(Ricinus communis)* were reduced by waterlogging and maximum plant growth reduction was occurred when the plants were imposed to waterlogging for 9 days (Pollane, 1995). Zhou *et al*. (1997) observed that plant height was decreased significantly by waterlogging at the seedling and stem elongation stages in sesame. In a pot culture experiment to study the effect of waterlogging on morpho

physiological character of sesame, maximum plant height was found under non waterlogging condition (Hossain and Salahuddin ,2001).

Increase in duration of waterlogging caused a decrease in branch number in sesame (Ghoi *et al.,* 1996). Waterlogging at seedling and stem. Waterlogging has reported to have significant effect on capsule number, capsule weight and time taken for capsule formation. Zhou *et al* (1997) and Hossain and Salahuddin (2001) found that number of capsules plant^{-1} was significantly reduced in sesame by waterlogging. Duration of Waterlogging significantly reduced the weight of capsules (Beltrao *et al.,* 1997). Rincon *et al.* (1997) observed that the water stress reduced duration of capsule formation and capsule number plant^{-1}. According to Choi *et al.* (1990) and Beltrao *et al.* (1997), longer period of waterlogging decreased 1000 seed weight in sesame. In contradiction to this, Hassan *et al.* (2001) reported that thousand seed weight was not affected due to waterlogging.

Excess water stress depending on duration and crop stage can affect crop growth and yield. In Soybean, flooding during vegetative stage caused reduction in yield and it was mainly due to decreased stem dry weight (Choi *et al*., 1990). Persistent waterlogging for four days and eight days during vegetative, flowering and capsule development stages significantly reduced the yield by 8-11% and 13-33% respectively (Sorte *et al.,* 1997). In rapeseed decrease in yield started from three days of waterlogging and it is mainly due to lower number of seeds per plant (Gutierrez *et al.,* 1997). Yadav and Srivastava (1997) reported that waterlogging during reproductive phase caused maximum reduction in yield in sesame. The seed yield plant^{-1} was reduced by 48 h of flooding (Hassan *et al.,* 2001). Mensah *et al*. (2009) reported that continuous flooding and severe drought adversely affected the crop resulting in low yield.

Plant height and root length in both waterlogging period and recovery period were shorter due to waterlogging than that of control condition. Plant height of genotypes BD-6980 (V1), BD-6985 (V2), BD-6992 (V3), BD-7012 (V4) at waterlogging period and recovery period were 9.3, 8.9, 16.8, 11.5cm and 33.3, 31.3, 34.9, 26.6 cm of waterlogging treated plant whereas 21.6, 18.4, 19.6, 18.6cm and 52.6, 49.3, 57.3, 40.1cm of untreated control plant. Similarly root length in both waterlogging period and recovery period among the

genotypes V1, V2, V3 V4 were 5.5, 7.4, 18.1, 8.3 cm and 12.9, 16.9, 12.0, 13.8 cm of waterlogging treated plant whereas 20.9, 13.8, 13.4, 15.4cm and 18.0, 19.8, 20.6, 13.4 cm of untreated control plant.

Dong *et al*. (1983) reported that longer duration of waterlogging affected root morphological factors like root dry weight, number of roots etc. and resulted in complete decay of the root in wheat. Normal root development was replaced by the adventitious roots and it eventually led to increase in number of roots compared to control (Mano and Omori, 2007). Satomi *et al.* (2015) studied differences in root development among ninety-two soybean lines during initial growth stages in response to flooding and reported that root dry weight, root length and root surface area are important indices of flood tolerance. Flooding reduced the root and plant dry weights but not shoot dry weight and these mean values varied widely in different lines in both flooded and controlled conditions. Total root length and root surface area were severely decreased by flooding.

Root volume and root dry weight also substantially reduced in response to waterlogging. It was observed that root volume reduced 66-85% at waterlogging period and 15-57% at recovery period in waterlogging treated plant of different genotypes compared to untreated control plant.

In case of root dry weight, it was reduced 28-81% at waterlogging period and 57-69% at recovery period in waterlogging treated plant compared to untreated. Leaf area also found smaller in all the genotypes i.e., 75 to 134 cm2 and 244 to 297 cm2 in waterlogging affected plant whereas 152 to258 cm2 and 399 to 509 cm2 during waterlogging period and recovery period, respectively.

SPAD reading which is the indicator of chlorophyll content of leaf showed higher value (40.7 to 44.4) in waterlogged plant than that of control plant (37.5 to 41.8) during waterlogging but it showed decreasing trend (38.7 to 40.7) in waterlogged plant than that of control plant (43.7 to 46.9) during recovery period waterlogging and recovery period.

Specific leaf mass also showed the similar trend with that of SPAD value. Specific leaf mass of different genotypes showed increasing trend (5.48 to 6.33) in waterlogged plant

than that of control plant (3.97 to 5.82) during waterlogging but it showed decreasing trend (4.86 to 5.87) in waterlogged plant than that of control plant (5.34 to 6.29) during recovery period. From these results it indicated that waterlogging stunted the leaf expansion but leaf content might be concentrated during the waterlogging period resulting the higher SPAD value as well as greater specific leaf mass. But during recovery period, waterlogged plant started to expand leaf size or produce new leaf which might have lower SPAD value and specific leaf mass under waterlogged plant than that of control plant.

Dry matter partitioning pattern of different components showed the lesser amount of dry mass in all the plant parts in waterlogged plant than that of control plant in both the waterlogging period and recovery period regardless of genotypes. Root and shoot ratio decreased in waterlogged plant (0.06 to 0.09 and 0.11 to 0.15) compared to that of control plant (0.11 to 0.19 and 0.14 to 0.17) in waterlogging period and recovery period, respectively (Figure 9). It was also observed that decreasing trend was slightly lower during recovery period than that of waterlogging period. It indicated that the plant might be recovered its root system compared to shoot.

Both test accessions were induced wilting and leaf chlorosis during waterlogging. But the symptoms occurred earlier in Ezhi-2, the older leaves of which became wilted and chlorotic after only 4 days of stress and after 15 days, this accession suffered close to 100% mortality. ZZM2541 leaves appeared normal up to 8 days of waterlogging, and by day 15, many vigorous adventitious roots had emerged from the submerged stem. Short-term waterlogging within 2 days induced a quick increase of plant height of the both accessions. The main root of ZZM2541 elongated sharply until day 4 under stress and then kept stable but longer than the control until day 8, while for the sensitive accession Ezhi-2, it just kept longer than the control before day 6 and performed to be suppressed obviously under durative waterlogging. The primary branch root number of ZZM2541 increased during all the waterlogging period, especially with a marked increase from day 4 to day 6 under waterlogging. In contrast, in Ezhi-2 the primary branch root number only increased before day 2 of treatment, and then rapidly decreased for obvious decomposing of roots.

2.3.1. Relative growth of plant components and waterlogging tolerance

The relative growth rate (RGR) of root, stem, leaf, petiole, shoot and total plant of both waterlogged and control condition of four sesame genotypes during recovery period showed the positive RGR in all the genotypes under control as well as waterlogged condition (Table 1). Among the genotypes, BD 6980 showed identical or greater values i.e., 0.15, 0.15, 0.09, 0.08, 0.11 and 0.12 RGR of root, stem, leaf, petiole, shoot and total plant of waterlogged plant compared to control plant (0.01, 0.14, 0.07, 0.09, 0.11 and 0.10 RGR of root, stem, leaf, petiole, shoot and total plant). Among the components, RGR of root under waterlogged condition was found higher (0.15, 0.18, and 0.13) or similar compared to control condition (0.01, 0.13 and 0.13) in all genotypes except BD 6992 (0.07 RGR at waterlogged plant and 0.14 RGR at control plant). Waterlogging tolerance (WLT) indices of root showed better performance except BD 6992. Among the genotypes, BD 6980 exhibited greater tolerance indices i.e., nearly 100% or more than 100% followed by BD 6985 which indicated the highly tolerant against waterlogging.

2.3.2 Anatomical responses to waterlogging

In the absence of stress, both accessions develop longitudinal lacunae in their root exodermis, separated by rows of parenchyma cells and surrounded by a ring of sclerenchyma cells. Under waterlogging, the ZZM2541 root generated an extensive lysigenous aerenchyma, organized radially in the root cortex. ZZM2541 roots, stems were characterized by the presence of plentiful aerenchymatous tissue. In leaves, it wasdiscovered no apparent intercellular spaces existing in the spongy mesophyll of both accessions. However, there discovered obvious aerenchymatous cells in epidermis of leaf veins in the stressed ZZM2541, but the collapse of parenchyma cells in the stressed Ezhi-2. In contrast, even the susceptive Ezhi-2 could form some disorganized aerenchyma, its collapsed cells, lead to a distortion of organ morphology, and disintegration of internal structure by 8 days of waterlogging.

The formations of aerenchyma and adventitious roots are characterized as common anatomical responses in waterlogged plants. These responses at anatomical level facilitate the oxygen capture for submerged tissues, alleviate the hypoxic conditions (T.D. Colmer,

2003; R.R. Suralta and A. Yamauchi, 2008), and contribute to the survival of plants in frequently waterlogged soils (L.A.C.J. Voesenek *et al*., 2006). ZZM2541 is an accession with relatively higher tolerance to waterlogging. At the morpho-anatomical level, its response to hypoxia is to develop aerenchyma in root and stem, as well as to form adventitious roots. However, it is not discovered that ZZM2541 is able to develop larger intercellular spaces in its spongy mesophyll, which help to oxygen capture and exchange within the submerged tissues in plants (T.D. Colmer, 2003). Efforts to investigate diverse genetic resources with comprehensive responses to waterlogging are urgent and critical for sesame breeding program. In contrast, even Ezhi-2 plant is able to respond in the formation of some disorganized aerenchyma in root and stem, its collapsed cells in root cortex and leaf parenchyma lead to a disintegration of internal structure, and cannot therefore sustain the oxygen supply to the waterlogged parts of the plant.

Most of the plants are very susceptible to waterlogging condition. Oxygen diffusion in water is 10^4 times less than that in air. So, roots surrounded by water have very less oxygen uptake and Adenosine triphosphate (ATP) production is greatly decreased with the oxygen deprivation, resulting in the lack of energy in waterlogged plants. This will lead to death of plants (Colmer and Voesenek, 2009). Formation of aerenchymatous tissue made up of large intercellular spaces and adventitious roots are important traits for waterlogging tolerance. Aerenchymatous tissue provides less resistance in internal pathway for the exchange of gases between aerobic shoot to the anaerobic root. The formation of aerenchyma is one of the most critical factors for waterlogging tolerant plants (Jackson and Armstrong, 1999). According to Marashi and Mojadham (2014), aerenchyma tissue in wheat (*Triticum aestivum*) was developed after increasing period of waterlogging. Maximum and minimum aerenchyma tissue formation was observed under two weeks and one week of waterlogging, respectively. Waterlogging duration for three weeks caused decay and change of aerenchyma tissues. In barley, faster formation of aerenchyma and adventitious roots are key factors for waterlogging tolerance in barley (Zhang *et al*., 2015).

Adventitious roots are developed from the submerged part of the stem in flooded plants and grow horizontally. Study of Garthwaite *et al*. (2003) revealed that adventitious root

number increased in an anoxia treatment compared with that in aerated conditions in barley and wheat. So, formation of aerenchymatous tissue and adventitious roots has significant role in flood tolerance.

Plants exhibit several anatomical changes under flooding/waterlogging condition. Under flooding/waterlogging condition, plants initiate adventitious root, hypertrophied lenticel, and/or aerenchyma (Ashraf 2012) for adjusting with the unfavorable condition. Although the exact physiological functions of lenticels are not yet clear, their connection with waterlogging tolerance in plants is evident (Parelle *et al*. 2006). It is thought that lenticels play a role in the diffusion of O2 and different gaseous substances involved in anaerobic metabolism which includes C2H2, CO_2, and CH4. Plants exposed to waterlogging resulted in distinct reduction in the seminal root diameter, stele diameter, and cortex thickness (Grzesiak *et al*. 1999). Vasellati *et al*. (2001) conducted an experiment with *Paspalum dilatatum* plants to elucidate the anatomical changes of plants under flooding condition. They observed few plastic responses under waterlogging: overgrowth of aerenchymatous tissue in the root cortex and the leaf sheaths and reduction in the number of root hairs and root length. In contrary, Correˆa de Souzaa *et al*. (2013) reported that root cortex of flooded seedlings did not show significant difference, but the width of exodermis was increased by 24% compared to well-aerated plants. Flooded condition also increased the width of phloem tissue and number of xylem vessel in the roots, while the area of xylem fibers decreased considerably. Among the different mechanism of maintaining root function of plants under flood stress, founding of tangential diffusion barriers is very important due to the reduction of radial O2 from the roots of waterlogged soil (Sauter 2013). However, maintaining O2 in the cells is necessary for the survival where aerenchyma takes part of a great role in allocating O2 from the shoot to the root. Waterlogging enhances the construction of aerenchymatous tissue in both wetland and dryland species (Colmer and Voesenek 2009; Shiono *et al*. 2011) which make them adaptive under waterlogging condition (Striker 2012).

The formation of internal gas spaces or aerenchyma is one of the most common adaptive features of plants under both waterlogging and flooding that facilitates flow and

distribution of oxygen from root to shoot (Colmer and Voesenek 2009; Shiono *et al*. 2011). Lysigenous aerenchyma in roots is generated by ethylene accumulation with subsequent programmed cell death (Shiono *et al*. 2008). The gas-filled spaces in cell or aerenchyma have been demonstrated in swollen stem and roots of *S. javanica* (Jackson 2006). Establishment of a lateral diffusion barrier is another important adaptive feature of flood- affected plants because it decreases radial oxygen loss from flooded roots (Sauter 2013). 1-Aminocyclopropane-1- carboxylic acid is converted to ethylene that is responsible for adventitious root formation (Shiono *et al*. 2008). Adventitious roots generate near water surface where the stem produces aerenchyma to get oxygen (Suralta and Yamauchi 2008).Porosity of roots of some plant species under flooding condition can be increased up to 53% to assist entry of oxygen (Justin and Armstrong 1987). Plants growing under flooded condition are characterized with an initiation of hypertrophied lenticels (Ashraf 2012). The development of lenticels in plants improved their waterlogging tolerance. Lenticels are believed to be involved in the downward diffusion of O2 and transportation of by-products of anaerobic metabolism such as ethanol, CO_2, and CH4 (Parelle *et al*. 2006). Reductions in stele diameter and cortex thickness have been reported in Z. mays plants exposed to waterlogging (Grzesiak *et al*. 1999). *P. dilatatum* plants showed increased aerenchymatous tissue in root cortex and leaf sheaths under flooding condition. High proportion of aerenchyma with the development of sclerenchyma was also noticed in *P. dilatatum*. The development of sclerenchyma is advantageous to prevent endodermis and stelar tissues, root, and leaf sheath from desiccation and also from collapse by soil compaction due to water pressure under flooded condition (Vasellati *et al*. 2001). In *Garcinia brasiliensis* (Clusiaceae), the thickness of exodermis increased by 23.70% under flooding condition compared to control. Flooding condition also increased phloem width and number of xylem vessels of roots (Correˆa de Souzaa *et al*. 2013).

2.3.3 Leaf chlorophyll and soluble protein content

In all green plants present on the surface of earth, chlorophylls form the most important pigment system since these are playing a key role in the conversion of solar energy into chemical energy. The relative chlorophyll content has a positive relationship with

photosynthetic rate. Chlorophyll includes chlorophyll a, b, c and d and chlorophyll a play a leading role in photosynthesis while chlorophyll b is secondary in function.

According to Valladares and Niinemets (2008) green pigment composition analysis in leaves is very important in plant eco-physiological studies. It gives information about physiological changes of plants under water stress conditions. Significant reduction in yield under waterlogged condition was caused due to increased leaf senescence and consequent reduction in the reproductive period in cowpea *(Vigna unguiculata)* (Umaharan *et al*., 1997). Wang *et al*. (1999) and Xu *et al*. (2012) reported that waterlogging treatment reduced photosynthesis and chlorophyll content markedly resulting in decrease in yield in sesame.

In both accessions, the mean leaf chlorophyll content increased rapidly to a peak on day 2 by 1.4-fold in Ezhi-2, and 1.2-fold in ZZM2541 during the early stage of waterlogging, and then declined progressively. It was shown that the decrease rate of the leaf chlorophyll content was less in ZZM2541, especially during the period from day 2 to day 6. After day 6, the leaf chlorophyll content in ZZM2541 was lower than that in non-waterlogged leaves. In contrast, it declined sharply in Ezhi-2 to a level less than that in non-waterlogged leaves after less than 4 days of waterlogging. The two accessions differed significantly from one another with respect to the induced level of this parameter, with the decrease in relation to non-waterlogged plants was 82% in Ezhi-2 but 18% in ZZM2541 after 8 days of waterlogging.

The soluble protein content in leaves and roots of both accessions overall kept decreasing during the waterlogging duration, and the lowest values were observed on day 8. The extent of decline in protein content in Ezhi-2 decreased to 65% and 53% in leaves and roots on day 8, respectively. The equivalent proportion in ZZM2541 was 88% and 8%, respectively. The decreased extents in the roots were more than those in the leaves, especially in ZZM2541.

2.3.4. Enzymatic Activities

Different enzymatic activities of the youngest fully expanded green leaves of sesame under control and waterlogged plants in both waterlogging period and recovery period Revealed

that the injury of biological lipid by reactive oxygen species (ROS) as indicated by Malondialdehyde (MDA) content was higher (14.41 to 14.70 nmol g-1 FW and 10.66 to22.03 nmol g-1 FW, respectively) in waterlogged 40 R. R. Saha *et al*. plant of all the four sesame genotypes in both waterlogging period and recovery period than controlled plants (9.92 to 13.7 nmol g-1 FW and 8.42 to 18.27 nmol g-1 FW) (Table 2 and 3). However, the rate of increment was lower in BD 6980 during waterlogging period which indicated that lesser oxidative stress injury than that of other genotypes. Different antioxidative enzyme activities including superoxide dismutase (SOD), peroxide (POD), catalase (CAT), ascorbate peroxide (APX) and glutathione peroxide (GPX) to encounter the deleterious effects of ROS showed differential responses in different genotypes due to imposition of waterlogging. SOD activity increased in BD 6980 and BD 6985 genotypes but decreased in BD 6992 and BD 7012 genotypes during waterlogging period. But it increased in all genotypes during recovery period. Catalase activities showed increasing trend at waterlogged plant in all the genotypes during both waterlogging and recovery period except BD 6985 during recovery period. Different peroxide activities such as POD, APX and GPX increased in waterlogged plant in all genotypes than that of control plant during both waterlogging and recovery period except slightly reduced activity of GPX in BD 6980 during recovery period.

Waterlogging stress can cause stomata closure, which will reduce CO_2 availability in the leaves and inhibit photosynthesis (Crawford, 1978). Thus, excessive excitation energy in chloroplasts could increase the generation of ROS and induce oxidative stress (Gossett *et al*., 1999). Hence, the ROS production in plants will increase under flooding stress (Ahmed *et al*., 2002). In the present study, the injury of biological lipid by ROS, as indicated by MDA content clearly increased in waterlogged plant. On the other hand, different antioxidant activities showed their capacity of defense system against ROS. It has been assumed that SOD has a control role in the defense against oxidative stress (Scandalias, 1993; Zhang *et al*., 2007). SOD removes superoxide radical by catalyzing its dismutation and one superoxide being reduced to H_2O_2 and another oxidized to O2(Hassanuzzaman *et al*., 2012). Catalase (CAT) is capable to dismutase two molecules of H_2O_2 to water and oxygen and thus it is considered as an efficient ROS detoxifier

(Hassanuzzaman *et al*., 2012). Peroxide (POD) also decomposed the H_2O_2 (Hwang *et al*., 1999). APX is vital for antioxidant defense because it is involved the maintaining the ascorbate pool and ascorbate has vital role in development of plant stress tolerance to adverse environmental conditions (Pastori *et al*., 2003). The GPX is another vital enzyme of 42 R. R. Saha *et al*. antioxidant defense system and it can efficiently scavenge H_2O_2 and thus provide protection against stress (Brigelius-Flohe and Flohe, 2003). Although, different antioxidant enzyme activities were found inconsistent in the present study but most of the antioxidant enzyme activities showed an increasing trend in waterlogged plant than that of control plant in all the genotypes. It is indicated that all the four genotypes seem to be moderately tolerant to waterlogging. Furthermore, genotypes BD 6980 having lower amount of MDA and simultaneously showed higher antioxidant activities which indicated highly tolerant to waterlogging stress.

2.3.5. Proline

Proline, also known as L-proline, is a non-essential amino acid having multifunctional role as important cytoplasmic penetrate and dehydrating agent which can improve the water holding capability of plant tissue and protect enzymes and membrane *in vivo* (Ma ,1994). Plants accumulate proline in cell under water logged condition (Xing and Cai, 1998) and has a key role on the defense mechanisms under various abiotic stresses (Nanjo *et al*., 2003). It is related also to the non-enzymatic detoxification of free radicals (superoxide, peroxide or hydroxyl) that are generated excessively under stress (Radyukina *et al*., 2008). Xu *et al*. (2012) reported increased proline content under flooding stress in all the three sesame genotypes of his study, proving the importance of proline under stress condition. Proline acts as an important osmolyte for osmotic adjustment and contributes to the stabilization of cell structures, protection of membranes and proteins against reactive oxygen species (ROS) (Steffens *et al*., 2012).

2.3.6. Super oxide dismutase (SOD)

Excessive formation of reactive oxygen species (ROS) is an integral part of many stress situations, including hypoxia. Super oxide dismutase (SOD) is an antioxidant present under abiotic stress condition and its activity is increased in cells under waterlogging and is vital

in the protection of plants against oxidative stress. Short anoxic stress increased the potential for superoxide production and it has a crucial role in the survival of the plant during flooding stress (Van Toai and Bolles, 1991). Yan *et al.* (1996) reported that prolonged flooding led to an increase in the activities of SOD in maize. Xu *et al*. (2012) reported that SOD activities in sesame leaves increased due to flooding and SOD activity in the flood tolerant sesame genotype WTG is increasing more than that of the susceptible genotype WSG.

2.3.7. Enzyme activity in the root

The increase in ADH and PDC activity was more pronounced in ZZM2541 than in Ezhi-2, while LDH activity was greater in Ezhi-2. By 6 days of waterlogging, the ADH activity in ZZM2541 was 9.23 U/g protein, much higher than in Ezhi-2 (5.62 U/g protein), meanwhile the LDH activity of Ezhi-2 (9.45 U/g protein) was three times that of ZZM2541 (2.62 U/g protein). ADH and LDH activity in Ezhi-2 peaked at, respectively, 2.3- and 5.4-fold their background level by day 6, and PDC activity peaked at 3.6-fold its background level by day 2. After peaking, the activity of all three enzymes fell rather rapidly. In ZZM2541, PDC reached a peak of activity of 5.9-fold their background levels by day 4 and it is followed that, ADH activity reached a peak of 8.9-fold their background levels by day 6 after a slowly increasing for 4 days. And its LDH remained at levels above background throughout the period of waterlogging.

2.3.8. Enzyme activity in the leaf

SOD activity remained above its non-waterlogged level after 2 days of waterlogging, and the most significant increase occurred after 6 days of waterlogging in both accessions (2.48-fold in Ezhi-2 and 4.28-fold in ZZM2541). As for the APX and CAT, there was a significant difference in the temporal pattern of their expression. After 2 days of waterlogging, APX activity in Ezhi-2 rose to 1.5-fold and CAT to 1.1-fold of their background levels, while in ZZM2541, the respective increases were 5.7- and 2.3-fold. Leaf MDA content in response to waterlogging is illustrated. In Ezhi-2, it was significantly higher in the waterlogged plants than in the non-waterlogged ones throughout the waterlogging period, increasing by about 1.3-fold (day 2) and 1.8-fold by day 6, and

subsequently declining. Anyway, its level in Ezhi-2 was still over 1.6-fold higher than that in ZZM2541 on the 8th day. In ZZM2541 leaves, the MDA content was largely unaffected by the waterlogging.

2.3.9. Plant responses to waterlogging

Excess rainfall, tides, floods, and lack of proper drainage facilities are the reasons causing waterlogging stress in plants. The primary effect of waterlogging in crop plants is anoxia or oxygen deprivation. Plants need oxygen for several unavoidable processes including cell division and growth, respiration, and uptake and transportation of nutrients. Chlorosis, necrosis, defoliation, growth reduction, reduced N fixation, yield loss, and plant death are effects of waterlogging stress in plants which are often occurring at various vegetative and reproductive stages (Hasanuzzaman *et al*. 2016).

2.3.10. Physiology and metabolism

Physiology and metabolism of plants are disrupted under waterlogging condition. Impaired stomatal conductance, gas exchange, CO_2 assimilation, and hydraulic conductivity of roots are some of the primary consequences in waterlogged plants (Ashraf 2012). Lone and Warsi (2009) observed that waterlogging stress had a great impact on few physiological traits in some crops. But leaf temperature remained mostly constant under both normal and waterlogged conditions in both winter and summer crop. Reduction of the net photosynthetic rate of wheat flag leaf was notable when the plants were remained under waterlogging condition (Zheng *et al*, 2009). Flooding frequently induces stomatal closing mostly in C_3 plants (Akhtar and Nazir, 2013) which hampers photosynthesis rate.

Liao and Lin (1996) observed that the reduction of leaf photosynthesis in bitter melon under waterlogging stress was associated with the decrease in transpiration, stomatal conductance, and the activity of ribulose-1, 5-bisphosphate carboxylase/oxygenase (RuBisCO). Kumar *et al*. (2013) reported that waterlogging results in the reduction of relative water content (RWC) and membrane stability index. However, these effects were more prominent in sensitive genotypes (MH-1K-24 and *Pusa baisakhi*) than tolerant genotypes (T-44 and MH-96-1). Photosynthesis rate decreased in all tested genotypes

under waterlogging stress, and these inhibitions increased in duration-dependent manner. Like photosynthesis rate, stomatal conductance also exhibited the same trend. In comparison with control plants, the respiration of leaf increased after 48 h of waterlogging. Sensitive genotypes also showed increased foliar respiration, while the minor reduction of respiration rate was recorded at sixth and ninth day of waterlogging. Moreover, foliar respiration in tolerant genotype was unchanged at any growth duration.

Therefore, they concluded that respiration of leaf did not reduce due to any tested duration of waterlogging. Flood stress involves different stressful situations for vegetation. Depth and duration of water during flooding determine the intensity of flood stress. Tolerant species of plants can survive under flooding/waterlogging condition through oxygenation of submerged tissues (roots and shoots) and above water leaves continuing carbon fixation. The uptake of CO_2 for carbon fixation maintained on mild days by active stomatal conductance even though stomatal closure for regulating plant water homeostasis at high atmospheric evaporative condition which helps to keep the balance between water uptake and transpiration loss.

Plants can be adopted to complete submerged condition by two main approaches, viz., low-oxygen quiescence syndrome (LOQS) and low-oxygen escape syndrome (LOES). The former is an effective strategy for plant survival, where the plant uses its reserve carbohydrates conservatively during the submergence period. When water falls down, plants showing LOQS restart their growth and development. The LOES involves upward elongation of shoots, which assists leaves exposed to the atmosphere. The plant species (or ecotypes) evoluted to shallow prolonged flooded environments showed these phenomena (Striker 2012).

The detrimental effect of waterlogging on water-loving plants has been reported in some studies. Anandana *et al*. (2015) recorded some damages in rice plant under long-time flooding stress. *Oryza sativa* cv. Puzhuthiikar showed notable enhancement of leaf blade length, sheath length, and area but reduction of leaf blade area. Accordingly, transpiration, rate of photosynthesis, and intercellular CO_2 were augmented in rice plant. In addition,

Pezeshki (2001) reported wetland vegetations acquire diverse characteristics that facilitate them to stay alive under saturated soil by adjusting soil chemistry such as redox potential (Eh). Decrease in Eh creates a situation where plant roots need to prepare themselves to uptake higher amount of oxygen. However, these phenomena are very common in wetland species, while the actual relationship between soil chemistry and plant physiological processes and the ultimate conclusion is still under study. Undoubtedly, extreme reduction in soil elevated oxygen demand exerts insightful influence on transportation and release of oxygen to the rhizosphere. Vandoorne *et al*. (2014) worked with Cichorium intybus plant and found that flooding stress enhanced the number of leaves but decreased the photosynthetic activity by closing stomata and reducing the efficiency of photosystem II (PSII). Under flooding condition, the roots of plant became shorter with no changes in fresh weight and dry weight. Roots of flooded plant accumulated glucose, fructose, sucrose, and 1-kestotriose but leaves accumulated organic acids and reducing sugars. Activities of invertase and sucrose synthase increased in both leaf and root, while the activity of sucrose-phosphate synthase remained unaltered due to flood stress. Synthesis of inulin was delayed in roots of flooded plants, and its mean degree of polymerization decreased as a consequence of the inhibition of fructan: fructan 1-fructosyltransferase.

2.4.1. Nutrient Availability

Flooding/waterlogging can break the balance of availability of different essential nutrients in soil that negatively affect numerous plant processes due to the unavailability or inefficiency of essential nutrients like N, K, Ca, Mg, etc. (Ashraf 2012). Reddy and Mittra (1985) reported that submergence led to the enhancement of N content of the plant tissues in duration-dependent manner. However, the submerged plants showed small amounts of P and K contents at any growth stages of the plant. Submergence also decreased the production of carbohydrates associated with the decomposition of proteins due to enhanced proteolytic activity. Since P and K deficiencies hold back, the synthesis of protein in plants accumulates some non-protein nitrogenous compounds which lead to increased N content in the tissue. Water stress-induced decrease in endogenous N, P, and K levels was reported in maize (Atwell and Steer 1990) and canola (Boem *et al*. 1996). Tarekegne *et al*. (2000) found great reduction of the uptake of Zn, Cu, K, and P in susceptible wheat genotype

grown under waterlogging. Due to the above-mentioned reasons, waterlogging results in nutrient deficiencies (Smethurst *et al*. 2005). Medicago sativa showed a noticeable reduction in the nutrient composition (K, P, Cu, Ca, Mg, Zn, and B) of leaf and root under waterlogging condition (Smethurst *et al*. 2005). Akhtar and Nazir (2013) also reported flooding potentially affected growth of plant and uptake of both macro- and micronutrients.

2.4.2. Yield

Except some water-loving plants, significant yield reduction occurs due to flooding or waterlogging. Flooding/waterlogging at any growth stage of plant ultimately hampers the yield of plant. Reddy and Mittra (1985) conducted an experiment with rice plant and showed that grain yield was adversely affected by full submergence. Maximum yield reduction (58%) was recorded from complete submergence at flowering stage. This reduction of grain yield was observed due to impaired anthesis as well as high sterility of flower. Around 69% unfilled spikelets were recorded in the experiment. Full submergence at seedling establishment stage reduced the grain yield by 29%, and submergence at maximum tillering stage reduced the grain yield by 18% in rice plant. Later on, Mensah *et al*. (2006) observed similar result in sesame plant. They observed that continuous flooding reduced the growth and seed yield of sesame plant. Flooding decreased dry matter accumulation, leaf number per plant, and ultimately the yield of sesame. Long-time flooding decreased the maturity time of sesame plant. It also stimulated chlorosis and abortion of flower. Lone and Warsi (2009) noted that grain yield of maize showed drastic reduction under excess soil moisture conditions in both winter and summer seasons. In winter trial, overall yield was higher in all the genotypes in both sets of experiments, but still yield loss (%) was higher. The yield reduction varies from 19% in YHPP45 (tolerant genotype) to 53% in Pop 3121_YHPP45. While in case of summer trial, overall yields were lower, but highest reduction in yield (66%) was detected in Tarun 83 (susceptible genotype), and lowest reduction (2%) was detected in YHPP45 genotype. Ezin *et al*. (2010)conducted an experiment and showed that the reaction of four tomato genotypes is quite different from each other under waterlogging condition. They found significant differences in the phenology of four genotypes under waterlogging condition. Flowering time and fruitset time were earlier in CLN2498E genotype than the genotypes CA4, LA1241, and

LA1579. Compared to control, the average fruit weight in LA1421 and CA4 genotypes varied noticeably when exposed to 8 days of waterlogging. Fruit-bearing habit and fruit yield were also negatively affected by waterlogging depending on the duration. Paltaa *et al*. (2010) detected that the temporary waterlogging decreased the seed yield by 54 and 44% in kabuli (Almaz) and desi (Rupali) chickpea cultivars, respectively. The lower seed yield in kabuli cultivars was mainly due to lesser pod number and number of seeds pod_1 under waterlogging condition. On the other hand, Yaduvanshi *et al*. (2010) reported that waterlogging imposition decreased grain yield in contrast to drained soils. However, the responses were greatly varied with genotypes and soil types. This differential response of wheat genotypes might be due to the function of different tolerance mechanisms under waterlogging. Rasaei *et al*. (2012) showed a significant difference among all the durations(10, 20, and 30 days) of the waterlogging stresses in wheat. The yield reduction up to 20 days was reasonable, but 30 days of waterlogging decreased the yield to 45% compared towell-drained condition. The yield of wheat under non-waterlogging condition and 10, 20, and 30 days of waterlogging were 7518.4 kg ha^{-1}, 6,815.5 kg ha^{-1}, 5,587 kg ha^{-1}, and 4,138.6 kg ha^{-1}, respectively. Kumar *et al*. (2013) carried an experiment with different genotypes of mung bean under waterlogging stress and found that yield was affected by waterlogging in all the genotypes. At vegetative stage, yield loss enhanced with duration- dependent manner. In average, grain yield losses in all mung bean cultivars were 20.01%, 33.79%, and 52% due to 3, 6, and 9 days of waterlogging, respectively. The tolerant genotypes were able to recover the grain yield losses caused by 3 days of waterlogging. On the other hand, for sensitive genotypes, even 3 days of waterlogging decreased the yield (up to 20%). In sensitive genotypes, grain yield losses were estimated at 70% (*Pusa baisakhi*) to 85% (MH–1K–24) after 9 days of waterlogging in comparison with control plants. Tolerant genotypes confirmed comparatively lower yield reduction even after 9 days of waterlogging. Amri *et al*. (2014) applied flooding stress to six genotypes of wheat for 28 days and noted that the grain yield affected significantly in all evaluated genotypes. Compared to rainfed conditions (control), waterlogging induced an average decrease of grain yield by 56% with a maximum of 74% recorded for cv. Ariana and cv. Vaga againsta lowest decrease of 39% recorded for the cultivars Salammboˆ and Utique. The two cultivars FxA and Haı¨dra showed an intermediate behavior with respective decreases of

60% and 48%. Prasanna and Rao (2014) conducted an experiment with waterlogging in green gram. They observed that the waterlogging condition for 2 days and 4 days considerably decreased the yield components and finally yield of green gram. The number of pods ANOVA, number of seeds pod_1, 100 seeds weight, harvest index, and yield of green gram decreased by 51%, 27%, 3%, 33%, and 71%, respectively, due to 4 days of waterlogging and by 29%, 14%, 1%, 13%, and 25%, respectively, due to 2 days of waterlogging in contrast to control plants. Very recently Ren *et al*. (2014) performed an experiment in the field for studying the effects of waterlogging for different durations (3 and 6 days) on the yield and growth of summer maize at the three-leaf stage (V3), six-leaf stage (V6), and the tenth day after the tasseling stage (10VT). The results after 2 years indicated that maize development and grain yield responses to waterlogging depended on both stress severity (intensity and duration) and different growth stages. Yield decreased significantly with an increased waterlogging duration during V3 and V6. The yields of maize hybrid Denghai 605 (DH605) in treatments V3-3, V3-6, V6-3, V6-6, 10VT-3, and 10VT-6 were 23%, 32%, 20%, 24%, 8%, and 18% lower than those of the control, respectively; yields of Zhengdan 958 (ZD 958) were decreased by 21%, 35%, 15%, 33%, 7%, and 12%, respectively, compared to control, under same treatments.

Seed yield was reduced in all the genotypes due to imposition of waterlogging i.e., 3.6 to 6.4 g plant^{-1}) whereas it was 6.5 to 9.9 g plant-1 in control condition. But reduction increment was found minimum (24%) in BD 7012 and maximum in BD 6980 (44%). Among the seed yield components, number of capsules per plant largely contributed to the seed yield which also showed similar trend with that of seed yield. Yield potentiality might due to genetic differences among the genotypes. Although BD 6980 was identified as highly tolerant genotype to waterlogging considering waterlogging tolerance and enzymatic activities but it produced lower seed yield in waterlogging as well as control condition. Setter and Waters (2003) also reported that highly tolerant lines may be low yielding genotype. With respect to reproductive success, a decline of photosynthesis will eventually result in limited resource availability for reproduction in parental and gametophytic tissues due to a reduction in energy reserves leading to plant starvation (Young *et al*., 2004; Sumesh *et al*., 2008). Thus, generating high yielding and stress-tolerant

crops require a thorough understanding of the metabolic and developmental processes involved not only in stress responses but also in energy regulation (Hirayama and Shinozaki, 2010).

As the duration of waterlogging increased, plant height got more affected. A severe in yield was observed due to waterlogging in case of both varieties. The rate of yield loss was rapidly increased with the increase of duration of logging. During the first year's study, maximum 39.41 % and 53.20 % of yield in comparison to the control treatment (normal drainage) were lost in case of varieties V1 and V2, respectively. Based on the first year's result, BARI Til 3 was found more susceptible to water logging in comparison to the BARI till 2. Relationship of yield versus duration of water logging in respect of different treatment and varieties. As observed, yield of both the varieties rapidly decreased with the duration of water logging. Although the trend of yield loss for both the varieties is similar, but comparatively steeper line of the variety V2 indicates its more susceptibility to water logging.

The results on the effect of duration of water logging on the two sesame varieties during the 2009-2010 cropping season. During study, all the agronomic parameters differed significantly among the treatments. As the duration of water logging increases, those parameters also got more affected. A drastic decrease in respect of yield was observed due to water logging in case of both varieties. The rate of yield loss was rapidly increased with the increase of duration of logging. Maximum 67.67 % and 65.61 % of yield loss in comparison to the control treatment (normal drainage) were observed in case of varieties V1 and V2. The variety V1 (BARI Til 2) and V2 (BARI Til 3) are almost equally susceptible to water logging. However, it was also observed that variety V1 was more susceptible short duration logging than variety V2. More than 47% yield loss was occurred in case of variety V1 only for 12 hours continuous logging at the two stages. Variety V2 is rather resistant to short duration logging than variety V1. It lost about 31% yield for 12 hours logging.

Relationship between yield and duration of water logging of the two-sesame variety.

As observed, yield of both the varieties rapidly decreased with the duration of water logging. The trend of yield loss for both the varieties is almost similar and a very little

difference was observed in the two response functions. From the two functions, it may be predicted that, if about 50 hours' continuous water logging is imposed at the two stages, the crop will be totally damaged. Except 1000-grain weight, all important agronomic parameters differed significantly to water logging. As the duration of waterlogging increased, those attributes also got more affected.

Yield of both varieties was decreased drastically due to water logging. The rate of yield loss was rapidly increased with the increase of duration of logging. As much as 67.67 % and 65.61 % of total yield in comparison to the control treatment (normal drainage) were observed in case of varieties V1 and V2, respectively. The variety V1 (BARI Til 2) and V2 (BARI Til 3) are almost equally susceptible to water logging. However, it was also observed that variety V1 was comparatively less susceptible to water logging than variety V2. However, for short duration of logging variety V1 was found slightly more susceptible than variety V2. More than 34% yield loss was occurred in case of variety V1 only for 12 hours continuous logging at two stages. Variety V2 is rather resistant to short duration logging than variety V1. It lost about 29% yield for 12 hours logging. Yield of both varieties rapidly decreased with the duration of water logging. The trend of yield loss for both the varieties is almost similar. A very little difference was observed in the two response functions as shown in Figure 3 From the two functions, it may be predicted that, if about 50 hours' continuous water logging is imposed at the two stages, the crop will be totally damaged. (P. K. Sarkar *et al*., 2016).

Excess water stress depending on duration and crop stage can affect crop growth and yield. In Soybean, flooding during vegetative stage caused reduction in yield and it was mainly due to decreased stem dry weight (Choi *et al*., 1990). Persistent waterlogging for four days and eight days during vegetative, flowering and capsule development stages significantly reduced the yield by 8-11% and 13-33% respectively (Sorte *et al.,* 1997). In rapeseed decrease in yield started from three days of waterlogging and it is mainly due to lower number of seeds per plant (Gutierrez *et al.,* 1997). Yadav and Srivastava (1997) reported that waterlogging during reproductive phase caused maximum reduction in yield in sesame. The seed yield plant^{-1} was reduced by 48 h of flooding (Hassan *et al.,* 2001).

Mensah *et al*. (2009) reported that continuous flooding and severe drought adversely affected the crop resulting in low yield.

2.4.3. Biochemical adaptation and hormonal regulations

Unlike other stresses, flooding or waterlogging leads to a deprivation of oxygen in plants and creates hypoxia or anoxia. Both morphological and anatomical adaptations are associated with a series of biochemical changes in plant cells which make them tolerant to excess water stress. In oxygen-deprived condition, the metabolic activities are adversely affected; in most of the cases, plant shifts its metabolism to anaerobic mode. In such case, ADH is the key enzyme involved in anaerobic fermentation that converts acetaldehyde into ethanol with the oxidation of NADH into NAD^+. Although this process cannot produce much ATP, it is one of the adaptive mechanisms in plants during waterlogging. Increase in ADH activity under waterlogging condition has been reported in many plants (Christine and Musgrave 1994; Zaidi *et al*. 2004; Srivastava *et al*. 2007; Sairam *et al*. 2008).

Bansal and Srivastava (2015) found higher activity of ADH in *Cajanus cajan* genotypes under waterlogging condition. However, the tolerant genotypes showed higher activity of ADH than sensitive ones. After 6 days of waterlogging, ADH activity increased more than four folds in ICPL84023 and more than two folds in MAL18 as compared to control. Bajpai and Chandra (2015) indicated that proline (Pro) might be one of the biochemical adaptive mechanisms of plants under waterlogging. In their experiment, they observed a marked increase in Pro content after 96 h of waterlogging, compared to control. Moreover, the tolerant genotype showed higher accumulation of Pro, compared to sensitive ones. Under waterlogging condition, increased Pro content was also reported in Casuarina (Olgun *et al*. 2008) and in wheat (Carter *et al*. 2006). Waterlogging-induced increase in soluble protein content is observed in maize (Rai *et al*. 2004). While investigating Corchorus capsularis – a moderate waterlogging-tolerant fiber crop, Parvin and Karmoker (2013) observed that total sugar content in the root increased by 24% after 21 days of waterlogging, while in the stem and leaves, it was increased up to 15% and 17%, respectively. After 3 days of waterlogging, Pro content was increased by 50% (Parvin and Karmoker 2013). Sairam *et al*. (2009) found different adaptive responses in terms of sucrose synthase and ADH

activity in two cultivated *V. radiata* genotypes, viz., T44 (tolerant) and *Pusa baisakhi* (susceptible) and *V. luteola* (wild). Waterlogging declined total and non-reducing sugars in all the genotypes and reducing sugars in *Pusa baisakhi*, while the content of reducing sugar increased in *V. luteola* and T44. Waterlogging condition for 8 days resulted in 20 and 15 times more ADH activity than initial stage in *V. luteola* and T44, while this increase was sustained only up to the 4 days in *Pusa baisakhi* (Sairam *et al*. 2009). This indicated a carbohydrate-based tolerance mechanism in *V. luteola* and T44 genotype. This increased activity of soluble sugar in tolerant genotypes enhanced the availability of reducing sugars, which sustained their energy requirement because it is a key enzyme responsible for the hydrolysis of sucrose to fructose and glucose under oxygen deprivation (Ruan *et al*. 2003). Sairam *et al*. (2009) also concluded that greater ADH activity is a factor contributing to their better survival under waterlogged condition.

Hormonal regulation is one of the adaptive responses in plants under waterlogging. Some morphological and anatomical changes are also directly related to hormonal changes. For instance, being a flood-sensitive species, *S. lycopersicum* showed its ability to produce adventitious roots to survive under anoxia which was associated with ethylene synthesis (Vidoz *et al*. 2010). Apart from the direct effect, ethylene also coordinates the balance of other phytohormones such as gibberellic acid (GA) and abscisic acid (ABA) and those that have specific adaptive function in plants including shoot elongation and adventitious root formation (Fukao and Bailey-Serres 2008).

2.5.1. ROS metabolism under waterlogging

Flooding/waterlogging stress causes oxidative damages due to generation of ROS (Bowler *et al*, 1992; Sairam and Srivastva 2002; Blokhina *et al*. 2003; Table 10.1). Under flooding/waterlogging condition, the photosynthetic electron transport chain (ETC) becomes over-reduced, causing the generation of several ROS and as a result the oxidative stress (Ahmed *et al*. 2002). Productions of ROS take places through different mechanisms, for example, when molecules of aerobic system come in contact with the ionizing radiations; this interaction results in the production of ROS. Flowing of electrons through

ETC may leak from their appropriate route and in the absence of any electron acceptor; these electrons react with oxygen for producing ROS (Ashraf 2009). Different cellular organelles such as mitochondria, chloroplasts, and peroxisomes are known as the sites for generation of ROS (Sairam and Srivastva 2002). It is evident that oxidative damage is more severe after de-submergence than submergence condition. The re-entry of air after de-submergence introduces higher oxygen concentration relative to the very low concentration under water. Injury of the submerged plant generally develops after de-submergence and is possibly caused by ROS (Reviewed in Ito *et al*. 1999). Both waterlogging and flooding condition create anaerobic environment which in turn lead to hypoxic and anoxic conditions for plants and as a result produce ROS in transition which is many folds higher than normal growing condition causing severe damage to plant cell (Ashraf 2009; Irfan *et al*. 2010; Halliwell and Gutteridge 1999). The OH• and their dismutation product, H_2O_2, can directly attack membrane lipids resulting in higher malondialdehyde (MDA) content and also inactivate SH-containing enzymes (Ahmed *et al*. 2002; Hossain *et al*. 2009).

Elevated level of H_2O_2 also can inhibit the activities of Calvin cycle (Ashraf 2012). Flooding/waterlogging condition affects nutrient and water uptake of plants. As a result, plants show wilting even in excess of water environment. Because under waterlogging condition, oxygen becomes unavailable for plant (Sairam *et al*. 2008). Zheng *et al*. (2009) reported that MDA content in chloroplasts of plant generally increased under water stresses indicating a more severe lipid peroxidation in chloroplasts due to the enhanced H_2O_2 production and of O_2•_ release and depressed activities of antioxidant enzymes in comparison with the control. Komatsu *et al*. (2010) showed differential ROS production in different G. max genotypes due to the variations of lining of germin-like protein with oxalate oxide or superoxide dismutase (SOD) activity within the cell wall under waterlogging stress. According to Sairam *et al*. (2011), *V. radiata* plants showed enhanced production of H_2O_2 in time-dependent manners where tolerant genotypes produced significantly lower amount of H_2O_2 than the susceptible one. Similar result was observed in S. indicum by Xu *et al*. (2012) where MDA contents of leaves increased by 8%, 2%, and 29% in cv. WTG-2541, WTG-2413, and WSG-EZhi2, respectively. Ashraf (2012) reported

that an enhanced ROS generation disrupted the integrity of membranes and reduced the efficiency of PSII under waterlogged condition. Increased MDA and H_2O_2 contents were monitored in root of Vigna sinensis plants under waterlogging stress (El-Enany *et al*. 2013). Most recently, Correˆa de Souzaa *et al*. (2013) observed that H_2O_2 content significantly increased after 40 and 55 days of flooding.

2.5.2. Antioxidant defense

The excess amount of ROS inside the plant cells generated due to waterlogging/ flooding stress should be kept in a balance state to continue normal metabolic processes of plant cell. An imbalance between the scavenging of ROS by plant's antioxidant defense system and production of ROS can result in excess accumulation of ROS in plant cell (Irfan *et al*. 2010). Plant's antioxidant defense system includes both the enzymatic antioxidants, i.e., CAT, SOD, ascorbate peroxide (APX), monodehydroascorbate reductase (MDHAR), dehydro-ascorbate reductase (DHAR), glutathione S-transferase (GST), glutathione reductase (GR), and peroxide (POX) and nonenzymatic antioxidants, i.e., glutathione (GSH), ascorbate (AsA), tocopherols, and carotenoids (Apel and Hirt 2004; Hasanuzzaman *et al*. 2012; Khan and Khan 2014; Khan *et al*. 2014, 2015, 2016a, b). These act coordinately in scavenging ROS and protecting cells from oxidative stress. In many plants, activation of antioxidant defense was considered as one of the prime prerequisite adaptive mechanisms under waterlogging stress. However, this defense system is largely dependent on the stress duration and plant genotypes (Table 10.2). Ascorbate and GSH are components of the Halliwell-Asada cycle. Ascorbate reacts with different ROS and functions as the substrate for APX. On the other hand, GSH is a cell redox regulator and a potent ROS scavenger. Therefore, maintaining the redox balance of GSH is effective for the detoxification of H_2O_2 (Arbona *et al*. 2008). Activities of different enzymes (APX, MDHAR, DHAR, and GR) of AsA-GSH cycle are important to reduce ROS generation and to recycle AsA and GSH. Moreover, SOD, CAT, peroxides (POD), GPX, etc. have been reported to play a vital role to cope with different kinds of stresses including flooding/ waterlogging. Marked increase in SOD, CAT, and POD activities were observed in C. cajan subjected to 2–8 days of waterlogging, while the activities were variable according to the duration of stress (Sairam *et al*. 2009). Later on, Sairam *et al*. (2011) observed the

enhancement of the activities of GR, SOD, and APX in V. radiata. Similarly, increases in the activities of different enzymes were recorded in Z. mays seedlings when subjected to varying degrees of waterlogging stress (Bin *et al*. 2010). In O. sativa, the tolerance to submergence stress (8 days) was positively correlated with the capacity of the antioxidant defense system (Damanik *et al*. 2010). Higher activities of SOD, CAT, APX, and GR were observed in tolerant varieties, compared to susceptible varieties. Similar results were also observed by Bin *et al*. (2010) in Z. mays seedlings. Zhang *et al*. (2007) reported that enhanced POX and CAT activities were considered as a trait of tolerant plant species under waterlogging stress condition which enable them to protect themselves against oxidative stress. Tan *et al*. (2008) detected increased POX activity in *T. aestivum*. Citrus leaves showed an increase in AsA redox system when exposed to waterlogging (Arbona *et al*. 2008). In contrary, Ahmed *et al*. (2002) reported that waterlogging decreased the activities of SOD, GR, CAT, and APX in *V. radiata*.

2.5.3. Use of Exogenous protectants in mitigating waterlogging/flooding stress

Exogenous protectants of different groups are widely being used in modern approaches of alleviating damage effects caused by abiotic stresses in plants. Unlike other abiotic stresses, the mechanism of waterlogging or flooding stress tolerance has been demonstrated as a more complex trait by several researchers (Setter and Waters 2003; Setter *et al*. 2009; Pangand Shabala 2010; Zhou 2010; Table 10.3). The reason underlying this fact is that waterlogging stress is correlated with a number of factors like climate, soil properties, plant species, plant development stage, duration and severity of waterlogging, and so on (Leul and Zhou 1999; Setter and Waters 2003; Setter *et al*. 2009; Arru and Fornaciari 2010). As a consequence of this complexity in understanding, there are hardly any studies that evinced the role of exogenous protectants in diminishing the damages caused by waterlogging stress. However, some derivatives of triazole have been used to serve this purpose. There are reports indicating their ability to protect plants from several stresses, and hence this triazole compounds were termed as “multiprotectants” (Fletcher and Hofstra 1990; Pinhero and Fletcher 1994; Lin *et al*. 2006). In 1996, Webb and Fletcher used paclobutrazol (C15H20ClN3O) as a seed priming agent in *T. aestivum* and exposed the seedlings to waterlogged condition for 4 weeks. They measured some growth parameters

and photosynthetic pigments at three different height levels of the stressed plants. Paclobutrazol (PBZ)-treated seedlings showed higher chlorophyll (chl) contents and lower damage symptoms compared to non-treated stressed seedlings. Their study concluded that PBZ protects *T. aestivum* seedlings from waterlogging-induced injuries. Leul and Zhou (1998, 1999) used another triazole named uniconazole (UCZ, C15H18ClN3O) to alleviate the damage of waterlogging in B. napus seedlings. They used it as foliar spray on waterlogged seedlings which resulted in increased growth, yield, enzyme (SOD, CAT, POD) activities, and Pro content and decreased lipid peroxidation, electrolyte leakage rate, and erucic acid content compared to the waterlogged seedlings alone (Leul and Zhou 1998, 1999). In Ipomoea batatas L. seedlings, PBZ application resulted in higher activities of antioxidative enzymes (SOD, CAT, APX, GR) and GSH and AsA content under waterlogging (5 days) condition (Lin *et al*. 2006). Later on, Habibzadeh *et al*. (2012) reported the role of tricyclazole (C9H7N3S) on the morphological and biochemical characteristics of waterlogged B. napus seedlings. The foliar spray of tricyclazole increased the amount of photosynthetic pigments and yield attributes under waterlogging. However, above-mentioned studies reveal that triazole group compounds have regulatory effects on the mitigation of stress damage and induction of tolerance against waterlogging. They can enhance the activities of antioxidant enzymes, increase chl content, and improve growth and yield (Webb and Fletcher 1996; Leul and Zhou 1999; Lin *et al*. 2006). Triazoles also increased the photosynthetic rate (Leul and Zhou 1998), protein, and soluble sugar contents (Yang *et al*. 1994) and decreased lipid peroxidation, electrolyte leakage, and harmful metabolite production (Leul and Zhou 1999; Lin *et al*. 2006). There are numerous studies that exhibited the improvement of genetic and molecular strategies to develop varieties tolerant to waterlogging (Zhou 2010). But there is hardly any literature available about protectants that possess the evidence of promoting waterlogging stress tolerance in plants other than these few triazole compounds. However, An *et al*. (2016) investigated the effect of 5-aminolevulinic acid (ALA) in improving waterlogging-induced oxidative damage in Ficus carica plants. The plants grown under waterlogging condition for 2–6 days resulted in higher production of O_2•_ and lipid peroxidation. On the other hand, the plants which were pretreated with 5–20 mg L_1 of ALA reduced leaf O_2•_production rate and MDA content which was associated with the enhancement of the activities SOD and POD in

ALA-pretreated plants (An *et al*, 2016). So, comprehensive studies on the mechanisms of plant responses to waterlogging are needed to discover the possible ways to alleviate the damages caused by waterlogging. It will also help in understanding the required characteristics and selection criteria of the protectants to be used against waterlogging stress.

Chapter III

MATERIAL AND METHODS

This chapter includes the general materials and methods covering the description of the experimental site, climate and soil. The section also described the specific materials and methods, especially relevant for a particular experiment. To meet research objectives of the present study, three experiments were conducted at Plant Physiology Laboratory and research farm of Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur for the growing seasons of *Rabi* from 2016-2018.

In that location different experiments were conducted with various treatment to observe the performance of genotypes under various waterlogging condition of sesame. As a result, all the seedlings of each genotype per replication were used for measuring of Root Length (RL), Shoot Length (SL), Full Length (FL), Full Fresh and Dry Weight and Waterlogging Tolerance Coefficient (WTC) under control and waterlogged conditions which were recorded for genotypes screening at BARI Plant Physiology Laboratory. Moreover, morphological data of sesame plant were also recorded. The plant height, numberof leaves per plant, number of branches per plant, shoot fresh weight (g), shoot dry weight(g), root fresh weight (g), root dry weight (g), root length, root shoot ratio was measured. Yield Contributing Data such as data of 1st flowering, data of 50% flowering, data of 1st Fruit set, data of maturity, number of pod plant, number of seed per plant, thousand seed weight, and harvest index also recorded. Sesame yield and yield contributing data also recorded. To get the insight of experimental effects, stated location details. Physiological, biochemical mechanism and anatomical analysis of water logging tolerance in sesame also examined.

3.1. Description of the experimental site

The field experiments were conducted at Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur. The Bangladesh Agricultural Research Institute (BARI) field is situated in the middle part of Bangladesh and located at 230 59'38" N *latitude*, 900 24'89" E *longitude* and 8.4 (m) *elevation*. The experimental site lies at AEZ-28 (Madhupur Tract

Agro-ecological zone) of Bangladesh. (FAO/UNDP, 1988). Location map have been given in (Appendix-I).

3.2 Soil characteristics

The soil belongs to "The Modhupur Tract", AEZ-28 (FAO, 1988). The BARI farm belongs to the General soil type, Shallow Red Brown Terrace Soils and Top soils were clay loam in texture, olive-gray with common fine to medium distinct dark yellowish-brown mottles, Soil pH 6.0-6.5. The experimental area was flat having available irrigation and drainage system. The land was above flood level and sufficient sunshine was available during the experimental period (Appendixes 1.2)

3.3 Climate of the experimental area

The climate of the locality is sub-tropical. It has characterized by high temperature, high humidity, and heavy rainfall during Kharif season (April to September) and low rainfall associated with moderately low temperature during Robi season (October to March). There are three distinct seasons in Bangladesh: a hot, humid summer from March to June; a cool, rainy monsoon season from June to October; and a cool, dry winter from October to March. In general, maximum summer temperatures range between 30°C and 40°C. May is the warmest month in most parts of the country. January (13˚C) is the coldest month, when the average temperature for most of the country is about 10°C. The temperature and relative humidity were also moderate and varied with the different seasons. The relative humidity was also relatively low and it was ranged from 50 to 70 on an average in *Rabi* season.

Experiment 1. Screening of different sesame genotype to various waterlogging stress at seedling stage under laboratory condition.

A practical breeding and selection program for a waterlogged situation requires that genotypes perform satisfactorily in appropriate waterlogged conditions. Clearly if selection and variety development can be done in waterlogged then the agronomic characteristics and performance can be assessed from the start. However, for a number of reasons this is not always practical and selection must be carried out in artificial systems. Such selection must be validated by waterlogged condition trials. All research works of this study were conducted at Plant Physiology Laboratory of Bangladesh Agricultural Research Institute (BARI) by the permission of honorable Vice-Chancellor of SAU and DG of BARI. The objective was to identify the useful genetic resources for waterlogged tolerant sesame accessions.

3.1.1. Experimental location

The experimental field was in Plant Physiology Laboratory of Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur

3.1.2. Experimental period

The experiment was started on 15 February, 2016.

3.1.3. Experimental objectives

To identify the useful genetic resources for waterlogged tolerant sesame accessions

3.1.4. Experimental materials

3.1.5. Seeds

The one hundred nineteen (119) selected genotypes were used as a plant material. These genotypes bear good phenotype characters and agronomic performance.

3.1.6. Sources of seeds:

Sesame seeds of different genotypes were collected from PGRC (Plant Genetic Resource Center), BARI, Joydebpur, Gazipur.

3.1.7. Description of the genotypes:

The genotypes of one hundred nineteen (119) sesame were selected to identify their adaptability capacity on water logging condition. To find out the varietal resistance and susceptible genotypes against water logged condition, collected different genotypes from different source of Bangladesh. The genotypes were also selected due to its stable and high yield in normal conditions.

3.1.8. Experimental treatments

Thirty healthy seeds of each genotype were selected and placed on moist filter paper in petri-dish. Seeds were grown in an incubator (EYELA LTI-700, Japan) under control condition (Temp, 25±2 °C; RH, 65-70%) for germination at 3 days. After 3-days, petri-dishes were transferred in a control growth room (temperature 25±2 °C with 60% relative humidity and light: dark, 8:16 h) and 10 ml distill water with 1,000-fold diluted Hyponex solution (Type: 5-10-5, Hyponex, Japan) were applied in each petri-dish. Thereafter, every day, 5ml Hyponex solution were added in each petri-dish to keep them moist and maintained the evaporation losses.

Table 1: List of different genotypes of sesame.

Sl No.	Name	Sl No.	Name	Sl No.	Name	Sl No.	Name
1	BD 6971	31	JP 14017	61	BARI tIl 4	91	JP 5
2	BD 6960	32	BD 7014	62	BD 7004	92	BD 6966
3	JP 01514	33	BD 6987	63	BD 6981	93	BD6995
4	BD 6979	34	JP 35-2	64	BD 6978	94	BD6980
5	BD 10167	35	BD 6962	65	JP 01411	95	BD7001
6	BARI Til 3	36	BARI Til 3	66	BARI Til 3	96	JP 00515
7	BD 7015	37	BD 7023	67	BD 6984	97	BD 7017
8	BD6986	38	BD 7006	68	BD 7000	98	BARI Til 4
9	BD7027	39	BD 6972	69	BD 7012	99	BD 7029
10	BD 6980	40	BD 10166	70	BD 6959	100	BD 7013
11	BD 6990	41	BD 6980	71	JP 14004	101	JP 160
12	BD 6964	42	BD 7009	72	BARI Til 4	102	BD 6999
13	BD 6992	43	BD 6982	73	BD 7026	103	GP 5
14	JP 14013	44	BD 6993	74	BD 7018	104	GP 21
15	BARI Til 4	45	BD 6983	75	BD 6968	105	GP 35-1
16	BD 6985	46	BD 7022	76	BD 6980	106	GP 35-2
17	JP 02513	47	JP 14016	77	BD 6996	107	GP 83-1
18	BD 7012	48	JP 00411	78	JP 01311	108	GP 83-3
19	BD 6961	49	BARI Til 4	79	BD 7003	109	GP 160
20	BD 6980	50	JP 01611-2	80	BD 6991	110	GP 181-1
21	BD 7019	51	JP 01711	81	BD 6998	111	GP 254
22	JP 10311	52	BD 6985	82	JP 01811	112	GP 694
23	BD 6974	53	BD10165	83	BARI Til 3	113	GP 964
24	BARI Til 4	54	JP 03013	84	BD 6994	114	GP 212
25	BD 10164	55	BD 7021	85	BD 6989	115	GP 00411
26	BD 7011	56	BD 6980	86	JP 83-3	116	GP 515
27	JP 35-1	57	BD 7008	87	BD 7020	117	GP 01311
28	BD 6988	58	JP 14003	88	BARITil 3	118	GP01411
29	BD 7005	59	BD 6970	89	BD 7007	119	GP1514
30	BARI Til 3	60	BD 6997	90	BD 7016		

After 5 days, uniform seedlings were selected and divided into five groups. One group were cultured with previous methods as the control and the others group were followed by treatment. Five uniform seedlings were selected and treated for 12 h, 24 h, 36 h,48 h, and 72 h waterlogging stress.

3.1.9. Treatments

1. Control (normal water supply)
2. 12 h Water stress (200 ml DW to avoid oxygen exchange with the air)
3. 24 h Water stress (200 ml DW to avoid oxygen exchange with the air)
4. 48 h Water stress (200 ml DW to avoid oxygen exchange with the air)
5. 72 h Water stress (200 ml DW to avoid oxygen exchange with the air)

3.1.10. Experimental design and layout

The experiment was laid out in a two factors Complete Block Design (CBD) with 3 replications.

3.1.11. Experimental Data:

3.1.11.1 Germination Percentage

Germination data were collected. All the seedlings of each genotype per replicate were used for measuring the number of germinated seedlings.

3.1.11.2 Root Length

Root length were measured with measuring tape in centimeter (cm). All the seedlings of each genotype per replicate were used for measuring the root length of germinated seedling.

3.1.11.3. Shoot Length

Shoot length were measured with measuring tape in centimeter (cm). All the seedlings of each genotype per replicate were used for measuring the shoot length of germinated seedling.

3.1.11.4. Full Length

Full length was measured with total length of root length and shoot length in centimeter (cm). All the seedlings of each genotype per replicate were used for measuring the full length of germinated seedling.

3.1.11.5. Full Weight

Full fresh weight was measured with measuring scale in gram (g). All the seedlings of each genotype per replicate were used for measuring the full fresh weight of germinated seedling.

3.1.11.6. Waterlogging Tolerance Coefficient

Under control and waterlogged conditions WTC were measured with reference to root length, full length, and full weight. All the seedlings of each genotype per replicate were used for measuring the WTC.

$$WTC = \frac{\text{Mean value of treated seedling}}{\text{Mean value of control seedlings}}$$

We also measure plant mortality 10 days later at treated petri-dish.

Plate 1: Plates showing the different activities of screening of different sesame genotype to waterlogging condition at seedling stage under laboratory condition.

Experiment 2. Response of different sesame genotypes to waterlogging stress

Response of different sesame genotypes to waterlogging condition to find out tolerant and susceptible sesame genotypes under various waterlogged condition for seedling better yield. As a result, pot culture experiment was conducted during summer season in a Completely Randomized Design (CRD) with ten genotypes in three replications. Waterlogging was imposed in different DAS (Days after Sowing) in the pot. Duration of waterlogging was 48 hours and water level were maintained 3 cm above soil surface by replenishing frequently. After the treatment period, pot was replaced from water tank and plants were allowed to grow to maturity.

3.2.1. Experimental location

The experimental field was in Pot house at Bangladesh Agricultural Research Institute (BARI) farm, Joydebpur, Gazipur.

3.2.2. Experimental period

The experiment was started on 14 March, 2016.

3.2.3. Experimental objectives

To find out tolerant and susceptible sesame genotypes under waterlogged condition for getting better yield.

3.2.4. Experimental materials

3.2.5. Seeds:

In this experiment tolerant and susceptible sesame genotype were used (selected from experiment-1) for confirmation of the study where waterlogging was imposed at vegetative and flowering stage.

3.2.6. Sources of seeds:

Sesame seeds of different types were collected from PGRC, Bangladesh Agricultural Research Institute (BARI) farm, Joydebpur, Gazipur.

3.2.7. Description of the genotypes:

In this experiment 6 relatively tolerant and 4 relatively susceptible sesame genotypes were used (selected from experiment-1). The genotypes of total sesame were selected according to their adaptability capacity on water logging condition. The resistance and susceptibility genotypes against water logged condition were collected different source of Bangladesh to test varietal resistance against water logged situation. The genotypes were also selected due to its stable and high yield and vegetative and flowering stage.

3.2.8. Experimental Treatments

The experiment was conducted during *Rabi* season, 2017-2018 in a Completely Randomized Design (CRD) with four replications. Potting mixture were prepared with sandy loam soil mixed with coir pith compost. Excess plants were thinned out and three plants per pot weremaintained. Waterlogging was imposed 30 days after sowing (D) in the pots, 40 days aftersowing (D) in the pots, 50 days after sowing (D) in the pots. Duration of waterlogging was48 hours and water level were maintained 2 cm above soil surface by replenishing frequently. After the treatment period, water was drained out from the pots and plants wereallowed to grow to maturity.

Factor A:

Different selected genotypes from Experiment-1

V_1 =BD 7008

V_2 =BD-6985

V_3 =BD-6998

V_4 =JP-00411

V_5 =JP-03013

V_6 =JP-14003

V_7 =JP 01811

V_8 =BD-6996

V_9 =BD-6991

V_{10} =GP 83-3

Factor B:

Water logging condition with different Dyas

T_1 = Control

T_2 = 30 d

T_3 = 40 d

W_4 = 50 d

3.2.9. Experimental design and layout

The experiment was laid out in a Completely Randomized Block Design (RCBD) with four replications.

3.2.10. Experimental Data:

Observations were recorded on individual plants of each replication in this experiment. The characters studied were morphological data of plant height, number of leaves plant^{1}, number of branches plant^{1}, shoot fresh weight, shoot dry weight of, root fresh weight of , root dry weight of , root length and root shoot ratio. The characters studied were yield contributing data, days of 1st flowering, days of 50% flowering, days of 1st fruitset, days of maturity, number of pod plant, and number of seed per plant, thousand seed weight (g) and yield (t/ha1^{-1}).

3.2.11 Plant height (cm)

Height of selected plants were measured from the soil surface to the top of the longest leaf by a graduated scale and recorded.

3.2.12. Number of leaves plant^{-1}

Number of leaves emerging from main stem of selected plants was counted at harvest and average was expressed as number of leaves per plant.

3.2.13. Number of branches plant^{-1}

Number of branches emerging from main stem of selected plants was counted at harvest and average was expressed as number of branches per plant.

3.2.14. Shoot fresh weight

Shoot weight of selected plants were measured by a graduated scale and recorded in gram (g).

3.2.15. Shoot dry weight

Shoot dry weight of selected plants were measured by a graduated scale and recorded gram (g).

3.2.16. Root length

Length of primary root was measured and recorded in centimeter (cm).

3.2.17. Root fresh weight

Randomly selected plant roots were collected and weight was taken in an electronic balance and recorded in gram (g).

3.2.18. Root dry weight

Randomly selected plant roots were collected, oven dried, weight was taken in an electronic balance and recorded in gram (g).

3.2.19. Days to 1st fruit set

Number of days taken for fruit set of the plants in each entry was recorded.

3.2.20. Days to maturity

Days taken to mature 75 percent of capsules in 75 percent of plants within each plot were recorded as days to maturity.

3.2.21. Pods plant^{-1}

Total number of seed-bearing capsules on each selected plant including those on main stem and primary branches was counted and recorded.

3.2.22. Seed plant^{-1}

Total number of seeds on each selected plant including those on main stem and primary branches was counted and recorded.

3.2.23.1000 seed weight

One thousand randomly selected seeds of each genotype were weighed and recorded in grams (g).

3.2.24. Yield plant^{-1}

Selected plants were uprooted, capsules were collected, uniformly dried, seeds were extracted and seed weight per plant was recorded in grams and count the total weight of seeds of the plot.

Plate 2: Plate showing response of different sesame genotypes to waterlogging condition.

Experiment III. Physiological, biochemical and molecular mechanism of water logging tolerance in sesame.

The physiological and biochemical responses of sesame to waterlogging stress was investigated. The dynamics and mechanisms of action of anaerobic proteins and antioxidant enzymes in waterlogged sesame were explored. The mechanisms of Reactive Oxygen Species (ROS) and methylglyoxal detoxification system in waterlogged sesame were examined. The mechanisms of anatomic adaptations in waterlogged sesame also were explored.

Two relatively tolerant and two relatively susceptible genotype which were identified from experiment-2 and were grown in pot under control and waterlogging at vegetative stage for 3 days. Pots were submerged in concrete house where water were kept in such a way that at least 3-5 cm of the stem remain under water for three days. At the end of stress, pots were bringing out from water and examined the all the physiological, biochemical and anatomical analysis.

3.3.1. Experimental location

The experimental field was in Plant Physiology Laboratory and Field laboratory BangladeshAgricultural Research Institute (BARI), Joydebpur, Gazipur,

3.3.2. Experimental period

The experiment was started on 22 April, 2018.

3.3.3. Experimental design and layout

The experiment was laid out in a Completely Randomized Block Design (CRD) with four replications.

3.3.4. Experimental objectives

To investigate the physiological and anatomical changes in sesame under waterlogging stress.

3.3.5. Genotypes and treatments:

Two relatively tolerant and two relatively susceptible genotype were grown in pot under control and waterlogging at vegetative stage for 72 hours. Pots were submerged in concrete house where water will be kept in such a way that at least 3-5 cm of the stem remain under water for three days. At the end of stress, pots will bring out from water and following data will be recorded.

3.3.6. Determination of leaf chlorophyll content

Chlorophyll content of leaf samples were estimated as per the procedure described by Arnon (1949). A weighed quantity of leaf sample (0.5g) was taken from third fully expanded leaf and it was cut into small bits. These bits were put into test tubes and incubated overnight at room temperature with 10 ml DMSO: 80% acetone mixture (1:1 v/v). The colored solution was transferred into a measuring cylinder and the absorbance was measured at 663 nm and 645 nm.

The chlorophyll content was calculated as mg/ using following formulae.

Chlorophyll ‘a’ = ((12.7 * A 663) – (2.69 * A 645) V) / 1000 * W.
Chlorophyll ‘b’ = ((22.9 * A 645) – (4.68 * A 663) V) / 1000 * W.
A - Absorbance at specific wavelengths
V -Final volume of chlorophyll extract in 80% acetone
W- Fresh weight of tissue extracted.

3.3.7. Measurement of leaf Relative Water Content (RWC):

Measurement of relative water content (RWC) during long-term drought stress was taken using the method adapted from Barrs and Weatherley (1962). Detached aerial parts of stressed plants (n = 5) were individually weighed to determine sample weight (W) at various time points. After the initial determination of the sample fresh weight, individual samples were placed into 50-mL tubes and hydrated overnight in 40 mL of deionized water to full turgidity under normal room light and temperature. The samples were then removed from water, residual leaf moisture was gently removed with filter paper, and samples were

immediately weighed to obtain a fully turgid weight (TW). Subsequently, the plants were dried in an oven at 65°C for 48 h, and dry weight was measured (DW).
RWC was calculated as RWC (%) = [(W − DW)/ (TW − DW)] × 100.

3.3.8. Determination of Proline

Proline colorimetric determination proceeded according to Bates *et al.,* (1973) based on proline's reaction with ninhydrin. Fresh leaf tissue (0.5 g) was homogenized in 10 mL of 3% sulfosalicylic acid in ice. The homogenate was centrifuged at 11,500 × *g* for 15min. 2 mL of the filtrate was mixed with 2 ml of acid ninhydrin and 2 ml of glacial acetic acid. After incubation at 100^0C for 1hr was cooled and 4 ml of toluene was added. The optical density of the chromophore containing toluene was read spectrophotometrically at 520 nm using toluene as blank. The amount of proline was determined by comparison with a standard curve.

Proline in nmol.mg^{-1} FW or in µmol. g^{-1} FW =
(Absextract – blank)/slope*Volextract/Volaliquot*1/FW

Where: Absextract is the absorbance determined with the extract, blank (expressed as absorbance) and slope (expressed as absorbance·nmol-1) are determined by linear regression, Volextract is the total volume of the extract, Volaliquot is the volume used in the assay, FW (expressed in mg) is the amount of plant material extracted. It is assumed that Absextract is within the linear range.

In plant tissues, proline typically ranges from 0.5 (unstressed) to 50 (stressed) µmol. g-1 fresh weight.

3.3.9. Superoxide Dismutase (SOD):

Activity was estimated based on the xanthine- xanthine oxide system (Mostofa *et al*., 2015). The reaction mixture contained enzyme solution, 50 mM K-P buffer, 2.24 mM nitro-blue tetrazolium (NBT), 0.1 units Catalase,
2.36 mM xanthine, and 0.1 unit of xanthine oxide (final volume 700 µL). Then the change in absorbance of the solution was recorded for 1 min at 560 nm, and the activity of SOD

was expressed as unit (amount of enzyme required to inhibit NBT reduction by 50%) min^{-1} mg^{-1} protein.

3.3.10. Peroxidase (POD):

activity was assessed following the method of Hemeda and Klein (1990). The reaction mixture contained 25 mM K-P buffer (pH 7.0), 0.05% guaiacol, 10 mM H_2O_2 and the enzyme solution (final volume was 700 µL). Activity was determined by the increase in absorbance at 470 nm for 1 min and the extinction coefficient of 26.6 mM^{-1} cm^{-1} was used because of oxidation of guaiacol during POD activity calculation.

3.3.11. Catalase (CAT) activity was determined following the procedure of Csiszár *et al.*, (2007) by monitoring the decline in absorbance at 240 nm for 1 min and due to degradation of H_2O_2, an extinction co-efficient of 39.4 M^{-1} cm^{-1} was used. The reaction mixture contained 50 mM K-P buffer (pH 7.0), 15 mM H_2O_2 and enzyme extract (final volume 700 µL).

Chapter IV

RESULTS AND DISCUSSION

This chapter includes the results and discussion covering the description of each experimental parameters, especially relevant for the particular experiment. The data have been presented in different tables and figures. Attempt taken to screening the relatively waterlogging tolerance in different waterlogged period at seedling stage in first experiment. In second experiment, yield and yield contributing parameters of different genotypes were studied under waterlogging condition which was a pot trial. In the third experiment, the above experiments were evaluated considering few anatomical and physiological parameters. The results have been discussed and all possible interpretations are given under the following headlines.

Experiment 1. Screening of different sesame genotype to waterlogging at seedling stage under laboratory condition

4.1.1. Mortality percent and survivability percent of sesame under waterlogging stress:

Screening of different sesame genotype was done at four different duration i.e., 12 h, 24 h, 48 h and 72 h waterlogging condition at seedling stage under laboratory condition to identify the tolerant sesame genotypes (Table 2-7). All the plants after 72 h waterlogged condition were died. Mortality percentage varied from 51.3 percent to 100 percent under 12 h to 72 h of waterlogging (Fig. 1). But no genotypes survived up to 72 h of waterlogging and maximum survival was recorded at 12 h and the genotypes were survived at 12 h, 24 h and 48 h of waterlogging (Fig 2). The 57 sesame genotypes were preliminary survived at 12 h from screening of one hundred nineteen genotypes to waterlogging and rest of them (62) were died (Table 2 and 3).

Among them BD-6985, BD-6998, BD-7003, BD-7004, BD-7008, BD-7018, JP-00411, JP-03013 and JP-14003 were found better tolerance regarding survivability compare to others whereas genotypes BD-6959, BD-6980, BD-6981, BD-6984, BD-6991, BD-6996, GP 83-3, GP 53-1, GP 5, JP-01811 and BARI Til 4 (Table 2, 4, 6) were found more susceptible compare to others.

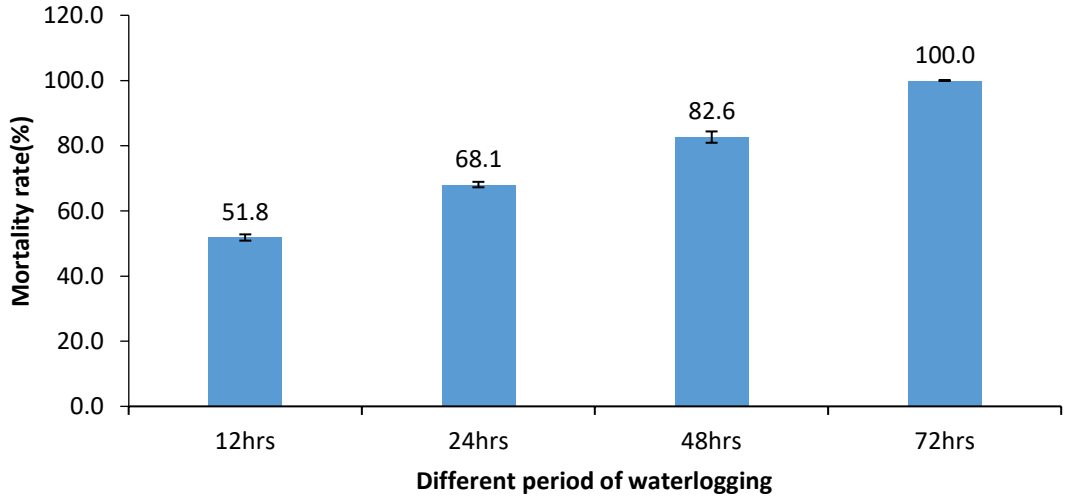

Figure. 1.: Average mortality rate of different seedling of sesame genotypes under different waterlogging period at 12 h, 24 h, 48 h, and 72 h

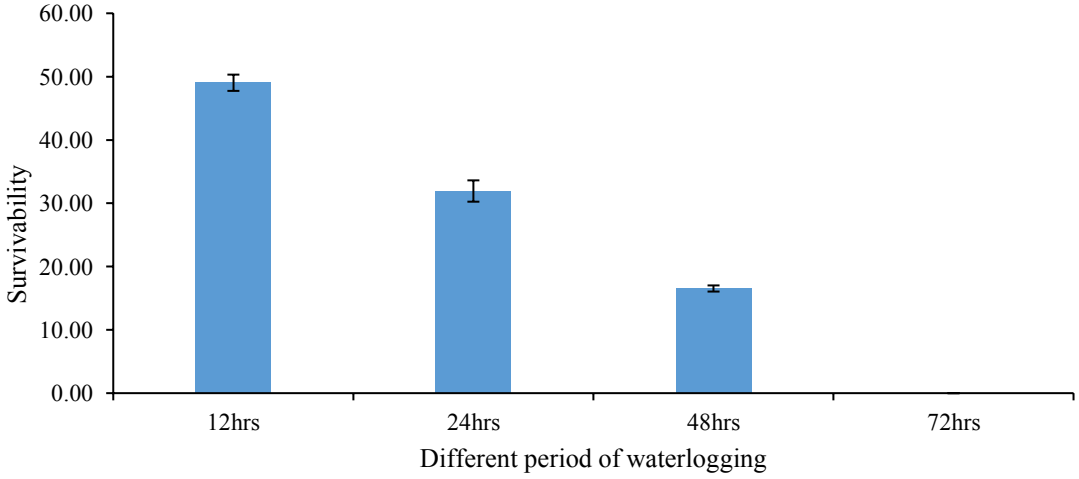

Figure. 2: Average survivability rate of different seedling of sesame genotypes under waterlogging conducted at 12 h, 24 h, 48 h, and 72 h

Martin *et al*. (2006) and Hussain *et al*. (2014) reported that plant responses to flooding stress in terms of survival percentage is a vital factor to assess the degree of waterlogging tolerance. Variability is directly related with genetic variability for flooding tolerance (Parelle *et al*., 2010). In rapeseed, waterlogging at the seedling stage showed a large diversity in survival ability and it was significantly correlated with the yield index (Zhou, 2014).

Table 2: List of 57 sesame genotypes out of 119 which were survive under waterlogging condition up to 12 h at seedling stage

Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name
1	BD 6960	2	BD 6979	3	BARI Til 3	4	BD6986	5	BD-6980
6	BD 6964	7	BARI Til 4	8	S. local	9	BD-7012	10	BD 6980
11	BD 6974	12	BD 7011	13	BD 7005	14	BD 6987	15	BARI Til 3
16	BD 6972	17	BD 6993	18	JP-140016	19	JP-00411	20	JP-01611-2
21	BD-6985	22	JP-03013	23	BD-7021	24	BD-7008	25	JP-14003
26	BD-6970	27	BD-6997	28	BD-7004	29	BD-6981	30	BD-6978
31	BD-6984	32	BD-7000	33	BD-6959	34	JP-14004	35	BD-7026
36	BD-7018	37	BD-6996	38	BD-7003	39	BD-6991	40	BD-6998
41	BD-6994	42	BD-6989	43	BD 7020	44	BD 7007	45	BD 6966
46	BD7001	47	JP 00515	48	BARI Til 4	49	BD 7013	50	GP-5
51	GP 21	52	GP-53-1	53	GP 35-2	54	GP 83-1	55	GP 83-3
56	GP 160	57	GP 694						

Table 3: List of 62 sesame genotypes out of 119 which were not survive under waterlogging condition up to 12 h at seedling stage

Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name
1	BD 6971	2	JP 01514	3	BD 10167	4	BD 7015	5	BD7027
6	BD 6990	7	BD 6992	8	JP 14013	9	JP 02513	10	BD 6961
11	BD 7019	12	JP 10311	13	BARI Til 4	14	BD 10164	15	JP 35-1
16	BD 6988	17	BARI Til 3	18	JP 14017	19	BD 7014	20	JP 35-2
21	BD 6962	22	BD 7023	23	BD 7006	24	BD 10166	25	BD 6980
26	BD 7009	27	BD 6982	28	BD 6983	29	BD 7022	30	BARI Til 4
31	JP 01711	32	BD10165	33	BD 6980	34	BARI tIl 4	35	JP 01411
36	BARI Til 3	37	BD 7012	38	BARI Til 4	39	BD 6968	40	BD 6980
41	JP 01311	42	BARI Til 3	43	JP 83-3	44	BARITil 3	45	BD 7016
46	JP 5	47	BD6995	48	BD6980	49	BD 7017	50	BD 7029
51	JP 160	52	BD 6999	53	GP 181-1	54	GP 254	55	GP 964
56	GP 212	57	GP 00411	58	GP 515	59	GP 01311	60	GP01411
61	GP1514	62	BARI Til 3						

Table 4: List of 38 sesame genotypes out of 57 which were survive under waterlogging condition up to 24 h at seedling stage

Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name
1	BARI Til 3	2	BD-6980	3	BARI Til 4	4	S. local	5	BD-7012
6	JP-140016	7	JP-00411	8	JP-01611-2	9	BD-6985	10	JP-03013
11	BD-7021	12	BD-7008	13	JP-14003	14	BD-6970	15	BD-6997
16	BD-7004	17	BD-6981	18	BD-6978	19	BD-6984	20	BD-7000
21	BD-6959	22	JP-14004	23	BD-7026	24	BD-7018	25	BD-6996
26	BD-7003	27	BD-6991	28	BD-6998	29	JP-01811	30	BD-6994
31	BD-6989	32	GP-5	33	GP 21	34	GP-53-1	35	GP 35-2
36	GP 83-1	37	GP 83-3	38	GP 160				

Table 5: List of 19 sesame genotypes out of 57 which were not survived under waterlogging condition up to 24h at seedling stage

Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name
1	BD 6960	2	BD 6979	3	BD6986	4	BD 6964	5	BD 6980
6	BD 6974	7	BD 7011	8	BD 7005	9	BD 6987	10	BARI Til 3
11	BD 6972	12	BD 6993	13	BD 7020	14	BD 7007	15	BD 6966
16	BD7001	17	JP 00515	18	BARI Til 4	19	BD 7013		

The 38 sesame genotypes were preliminary survived at 24 hrs from screening of 57 genotypes at seedling stage (Table 5).

Table 6: List of 16 sesame genotypes out of 38 which were survived under waterlogging condition up to 48 h at seedling stage

Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name
1	BARI Til 4	2	JP-00411	3	GP 83-3	4	BD-6985	5	JP-03013
6	BD-7008	7	JP-14003	8	GP-53-1	9	GP-5	10	BD-7004
11	BD-6959	12	BD-7018	13	BD-6996	14	BD-6991	15	BD-6998
16	JP-01811								

Table 7: List of 22 sesame genotypes out of 38 which were not survived under waterlogging condition up to 48 h at seedling stage

Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name	Sl No.	Genotype name
1	BARI Til 3	2	BD-6980	3	JP-140016	4	S. local	5	BD-7012
6	BD-7021	7	BD-6981	8	JP-01611-2	9	BD-6984	10	BD-6997
11	BD-7026	12	GP 160	13	GP 83-1	14	BD-6970	15	GP 35-2
16	GP 21	17	BD-6989	18	BD-6978	19	BD-6994	20	BD-7000
21	BD-7003	22	JP-14004						

Finally, 16 sesame genotypes were survived at 48 hrs from screening of 38 genotypes those were survived at 24 hrs to waterlogging and rest of them were died (Table 6). The genotypes were namely-: D-6998, BD-6985, JP-00411, JP-03013, JP-14003, BD-7004, BD-7008, BD-7018, BD-6991, BD-6996, JP-01811, GP 83-3, GP 53-1, BD-6959, BARI Til 4, and GP-5. Other 22 genotypes failed to survive under waterlogging condition up to 48 hrs duration (Table 7). All the seedlings of BD-6998 were survived (100%) up to 48 h waterlogging condition. The 90% were survived JP-00411, JP-03013, JP-14003, BD-7004, Bd-7018, and 60% were survived BD-6991, BARI Til-4, and 50% were survived GP 53-1, BD-6959, GP-5, and 40% were survived BD-6996, JP-01811, GP 83-3. These results

suggest that these different 16 sesame genotypes have different level of waterlogging tolerance at seedling stage.

Table 8. Pattern of survivability percent of sixteen sesame genotypes to waterlogging condition at 12 h, 24 h and 48 h

Period of waterlogging (h)									
SL No.	**Genotypes**	**12h**	**24h**	**48h**	**SL No.**	**Genotypes**	**12h**	**24h**	**48h**
1	BD-6998	100	100	90	9	BD-6991	100	80	60
2	BD-6985	100	100	100	10	BD-6996	100	70	40
3	JP-00411	100	100	90	11	JP-01811	100	60	40
4	JP-03013	100	100	90	12	GP 83-3	100	70	40
5	JP-14003	100	100	90	13	GP 53-1	100	70	50
6	BD-7004	100	90	90	14	BD-6959	100	70	50
7	BD-7008	100	100	100	15	BARI Til 4	100	65	60
8	BD-7018	100	90	90	16	GP-5	100	65	50

Waterlogging was imposed at four different duration i.e., 12 h, 24 h, and 48 h. After the treatment, water was drained out and survival percentage was recorded (Table 8). All the sixteen genotypes were survived in 12 h, 24 h and 48 h of waterlogging conditions. Survival percentage varied from 40 percentage (BD-6991) to 100 percentage (BD-6998) under 48 h of waterlogging. All 16 genotypes showed 100% survivability at 12 hrs waterlogging condition. The rate of survivability is gradually decreasing with the increasing of waterlogging duration, 24 hrs and 48 hrs. Among the cultivated genotypes, maximum survival was recorded by BD-6998 (100%) and minimum by BD-6991 (40%) at 48 h (Table 8).

4.1.2. Shoot length and Root length

Shoot length

The shoot length of sesame genotypes showed significant variation under waterlogging condition (Fig. 3).

The minimum reduction of shoot length was recorded in BD-6998, BD-6985, JP-0041, JP-03013, JP-14003, BD-7004, BD-7008, and BD-7018 sesame genotypes (Fig 3). These genotypes showed minimum percent inhibition of shoot length 29.05%, 20.42%, 39.70%, 26.92%, 27.94%, 38.70%, 24.48%, and 32.99% respectively. Because they recorded their shoot length 3.68, 3.61, 3.89, 3.80, 3.95, 4.21, 3.46, 4.42 cm at control and 2.61, 2.88, 2.35, 2.78, 2.85, 2.58, 2.61, 2.96 cm at 48 hrs waterlogging condition.

The maximum reduction shoot length was found in BD-6991 and minimum reduction of shoot length were found in BD-6998. BD-6991, BD-6996, JP-01811 and GP 53-1 at waterlogging period at 48 h were 4.03cm, 3.74cm, 4.26cm and 4.25cm at control condition. These plants were more susceptible compare to GP-83-3, BD-6959, BARI Til 4, GP-5 and JP-016112 because of the shoot length of those plants were 4.76cm, 4.73cm, 4.37cm, 4.55cm and 4.55cm at control (Table :9; Fig. 3). Moreover, shoot length of genotypes BD-6991, BD-6996, JP-01811 and GP 53-1 at waterlogging period at 48 h were 0.75cm, 0.56cm, 0.65cm and 1.05cm at waterlogged condition. These seedlings were more susceptible compare to GP-83-3, BD-6959, BARI Til 4, GP-5 and JP-016112 because of the shoot length of those seedlings were 0.66cm, 1.15cm, 0.95cm, 0.84cm and 0.97cm at waterlogged condition (Fig. 3). These results suggest that the genotypes which showed lower reduction of shoot length believe to better performance under excess water stress. The following genotypes BD-6991, BD-6996, JP-01811 and GP 53-1 exhibited better perform than GP-83-3, BD-6959, BARI Til 4, GP-5 and JP-016112.

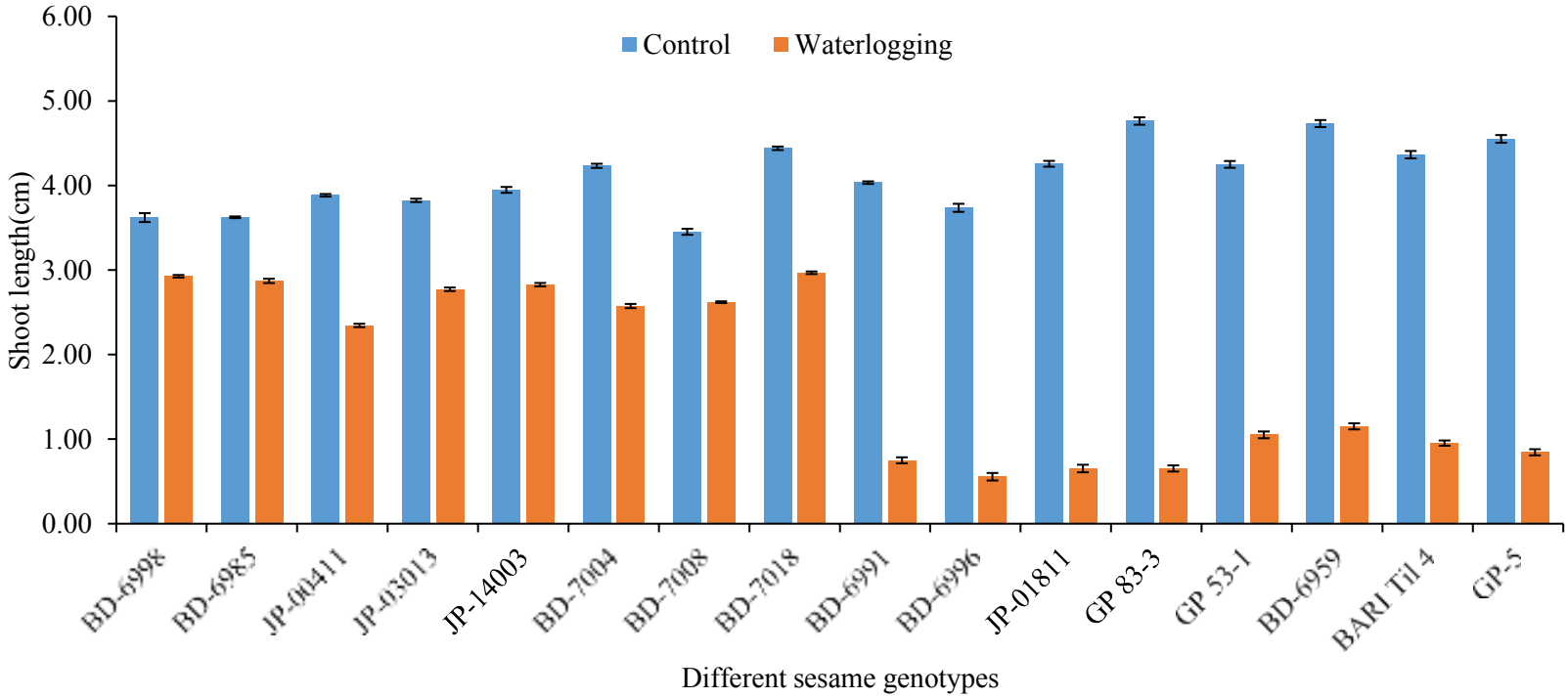

Figure 3. Shoot length of different sesame genotypes under waterlogging condition up to 48 h at seedling stage. LSD $_{(0.05\%)}$ =0.0553. (Error bar are shown value of standard deviation)

Shoot length of genotypes BD-6998, BD-6985 and BD-7008 at waterlogging period at 48 h were 3.62cm, 3.62cm, and 3.45cm. Those plant were more tolerant compare to JP-00411, JP-03013, JP-14003, BD-7004 and BD-7018 because of the length of those plants were 3.89cm, 3.82cm, 3.95cm, 4.23cm and 4.44cm (Table 9; Fig. 3).

Root length

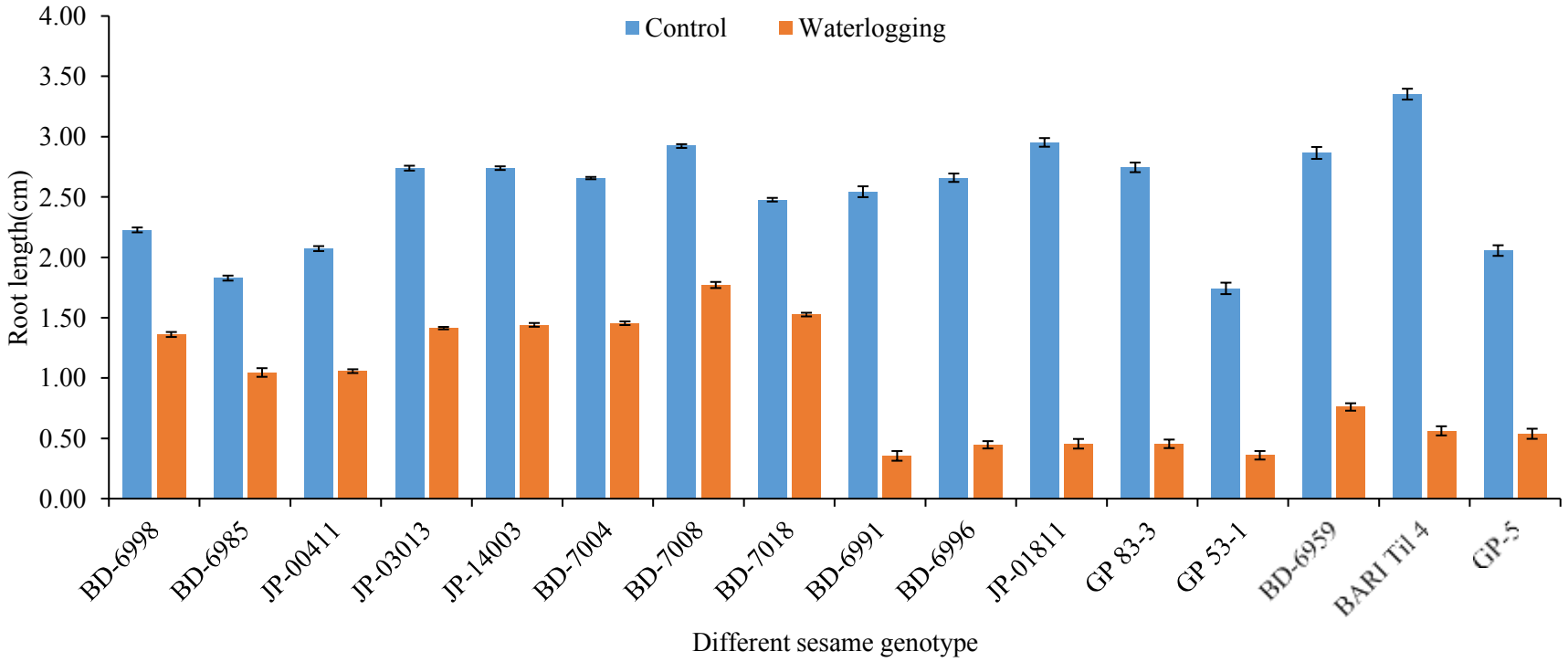

Figure. 4. Root length of different sesame genotypes under waterlogging condition up to 48 hrs at seedling stage. LSD $_{(0.05\%)}$ = 0.0317. (Error bar is shown value of standard deviation)

Root length of sesame genotypes showed significant variation under waterlogging condition (Fig. 4). The maximum reduction root length was found in BD-6991 and minimum reduction of root length were found in BD-6998. Root length of genotypes BD-6991, BD-6996, GP-5 and GP 53-1 at waterlogging period at 48 h were 2.54cm, 2.66cm, 2.06cm and 1.74cm at control condition. These plants were more susceptible compare to GP-83-3, BD-6959, BARI Til 4, JP-01811 because of the root length of those plants were cm, 2.95cm, 2.87cm, 3.35cm, 2.95cm and 3.46cm at control (Table. 9; fig 4). Moreover, root length of genotypes BD-6991, BD-6996, GP-5 and GP 53-1 at waterlogging period at 48hours were 0.35cm, 0.45cm, 0.36cm and 0.54cm at waterlogged condition.

These plants were more susceptible compare to GP-83-3, BD-6959, BARI Til 4, JP-01811 and JP-016112 because of the root length of those plants were 0.45cm, 0.75cm, 0.56cm, 0.46cm and 0.46cm at waterlogged condition (Fig. 4). Root length of genotypes BD-6998, BD-6985 and JP-00411 at waterlogging period at 48hours were 2.23cm, 1.83cm, and 2.07cm. Those plant were more tolerant compare to BD-7008, JP-03013, JP-14003, BD-7004 and BD-7018 because of the length of those plants were 2.92cm, 2.74cm, 2.74cm, 2.66cm and 2.48cm (Fig. 4; Table 9, Appendix 9). These results suggest that the genotypes which showed lower reduction of root length believe to better performance under excess waterstress. The following genotypes BD-6991, BD-6996, GP-5 and GP 53-1 exhibited better perform than GP-83-3, BD-6959, BARI Til 4, JP-01811.

Table 9. Percent of inhibition of shoot and root length of different sesame genotypes under waterlogging condition at 48 hours

Genotype	Shoot length (cm)		Percent inhibition at 48 h	Root length (cm)		Percent inhibition at 48 h
	Control	Waterlog up to 48h		Control	Waterlog up to 48 h	
BD-6998	3.68 k	2.61 d	29.05 j	2.23 h	1.37 e	38.62 o
BD-6985	3.61 k	2.88 b	20.42 m	1.82 j	1.04 g	43.12 m
JP-00411	3.89 h	2.35 e	39.70 g	2.10 i	1.07 f	48.74 i
JP-03013	3.80 i	2.78 c	26.92 l	2.72 d	1.40 d	48.36 j
JP-14003	3.95 g	2.85 bc	27.94 k	2.74 d	1.46 c	46.85 k
BD-7004	4.21 e	2.58 d	38.70 h	2.65 e	1.47 c	44.53 l
BD-7008	3.46 l	2.61 d	24.48 n	2.92 b	1.80 a	38.42 p
BD-7018	4.42 c	2.96 a	32.99 i	2.47 g	1.51 b	39.00 n
BD-6991	4.03 f	0.75 j	81.45 c	2.50 f	0.26 m	89.68 b
BD-6996	3.72 j	0.51 m	86.32 a	2.62 e	0.42 k	84.09 d
JP-01811	4.29 e	0.61 l	85.83 b	2.96 b	0.46 k	84.60 c
GP 83-3	4.71 a	0.67 k	85.88 b	2.71 d	0.26 m	90.47 a
GP 53-1	4.24 e	1.01 g	76.17 f	1.73 k	0.36 l	79.30 f
BD-6959	4.72 a	1.12 f	76.20 f	2.89 c	0.77 h	73.44 h
BARI Til 4	4.39 d	0.93 h	78.84 e	3.31 a	0.59 I	82.18 e
GP-5	4.56 b	0.88 i	80.58 d	2.09 i	0.50 j	75.82 g
$LSD_{(0.05\%)}$	0.06	0.039	0.129	0.05	0.0313	0.08
CV (%)	0.89	1.35	0.14	1.28	2.02	0.07

4.1.3. WTC with reference to shoot length of different sesame genotypes under waterlogging up to 48 hours with reference to length at seedling stage.

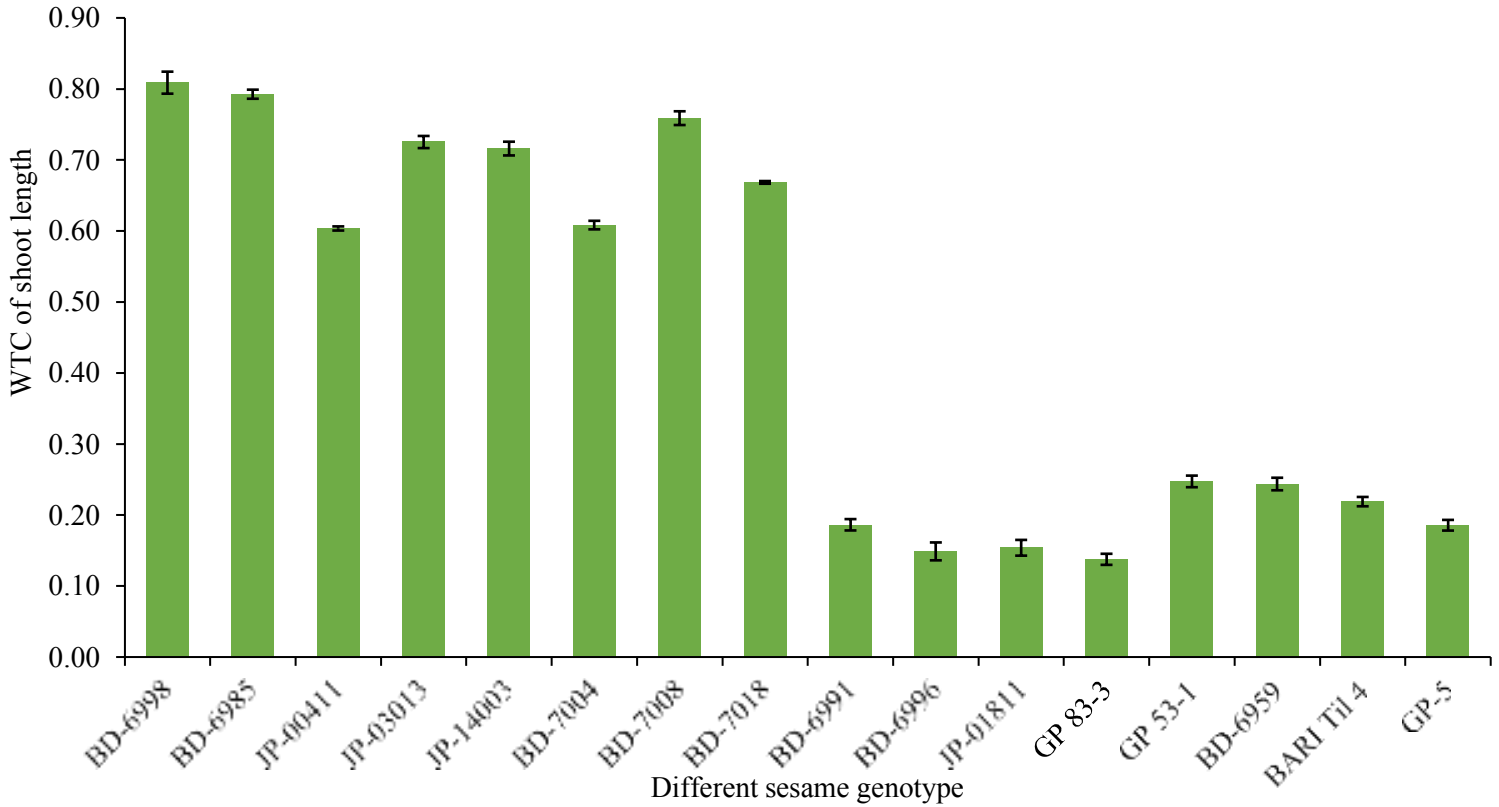

Figure. 5: Waterlogging tolerance co-efficient (WTC) with reference to shoot length of different sesame genotypes under 48 hours waterlogging period. LSD $_{(0.05\%)}$ =0.0117. (Error bar shown value of standard deviation).

The waterlogging tolerance coefficient (WTC) with reference to shoot length showed significant difference under waterlogging condition at 48 h (Fig. 5). The WTC was expressed tolerance and susceptible capability of a plant under waterlogged condition. Higher WTC expressed greater tolerant to waterlogged condition. Waterlogging tolerance co-efficient (WTC) of shoot length of genotypes BD-6991, BD- 6996, JP-01811 and GP-83-3 at waterlogging period at 48hours were 0.185, 0.136, 0.141 and 0.141. These plants were more susceptible compare to GP-53-1, BD-6959, BARI Til 4, GP-5 because of the WTC of those plants were 0.238, 0.238, 0.211, 0.194 and 0.206 (Table,10; Fig.5). Therefore, BD-6991, BD-6996, JP-01811 and GP-83-3 were susceptible genotypes. These results are partially consistent with the findings of Zhou *et al*. (2014) and Sarkar *et al.* (2016) who stated that waterlogging commonly damages the seedling establishment stage. The WTC was expressed tolerance and susceptible capability of a plant under waterlogged condition. Waterlogging tolerance co-efficient (WTC) of shoot length of genotypes BD-6998, BD-6985 and BD-7008 at waterlogging period at 48hours were 0.791, 0.795, and 0.755. Higher WTC believe to express tolerant to waterlogged condition compared to lower WTC believe to express susceptible to waterlogged condition. Those plant were more tolerant compare to JP-00411, JP-03013, JP-14003, BD-7004 and BD-7018 because of the WTC of those plants were 0.603, 0.730, 0.720, 0.612 and 0.670 (Fig. 5; table, 10). Therefore, BD-6998, BD-6985 and BD-7008 showed more tolerance than other sesame genotypes. It has been reported that tolerance level differed between wild species, *Sesamum malabaricum* and cultivated *Sesamum indicum*. *Sesamum malabaricum* recorded cent percent seedling survival to stress waterlogging condition and findings also showed that inntra specific variation for flood tolerance was also observed. Seventeen genotypes of *Sesamum indicum* survived waterlogging and twelve genotypes could not withstand the waterlogging condition. Similar varietal difference was reported by Zhou *et al*. (2014) in rapeseed.

Therefore, all together it indicates that WTC with reference to shoot length of different sesame genotypes have diverse range of tolerance and/or so susceptibility abioticstress including waterlogging conditions.

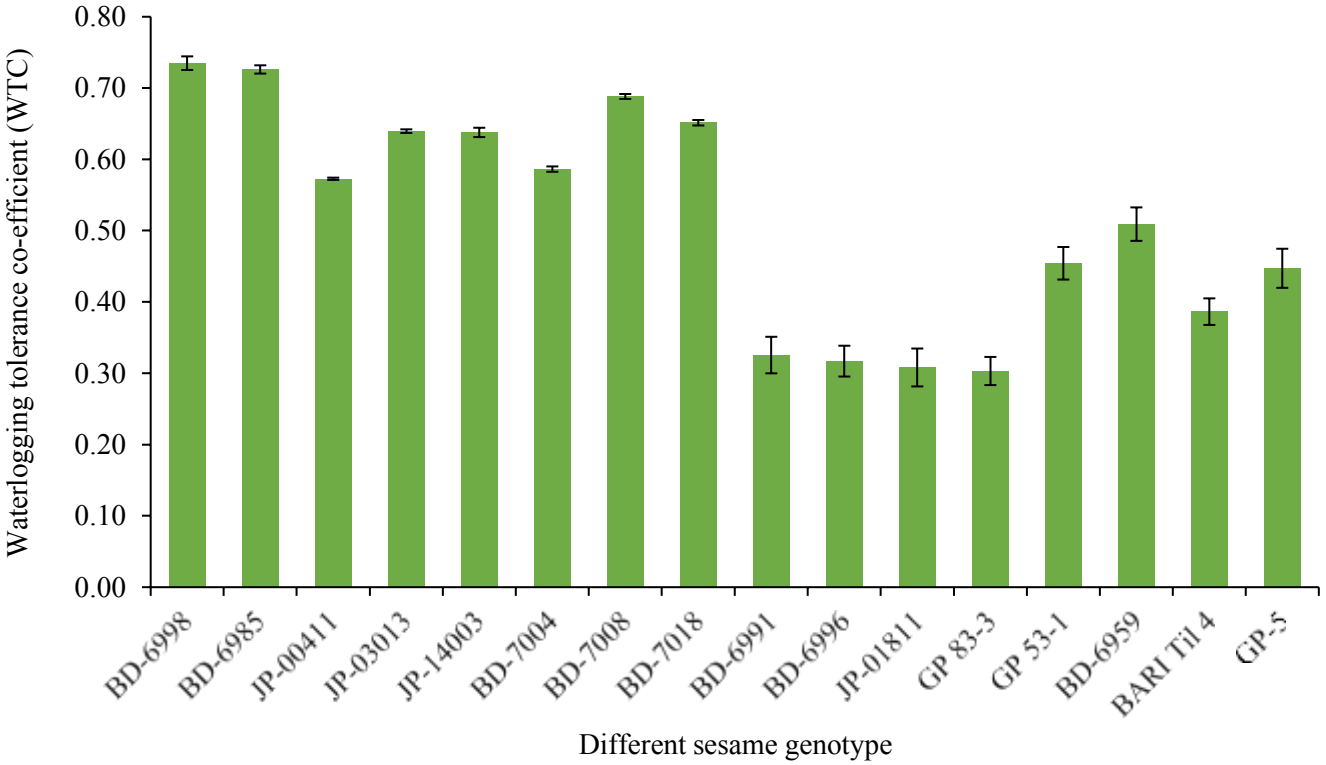

Figure. 6. Waterlogging tolerance co-efficient (WTC) with reference to root length of different sesame genotypes under 48 hours waterlogging period. LSD $_{(0.05\%)}$ = 0.0254. (Error bar shown value of standard deviation).

The WTC with reference to shoot length of different sesame genotypes showed significant difference under waterlogged condition at 48 6 (Fig. 6).

The WTC was expressed tolerance and susceptible capability of a plant under waterlogged condition. Waterlogging tolerance co-efficient (WTC) of root length of genotypes BD-6998, BD-7008 and BD-7018 at waterlogging period at 48 hours were 0.613, 0.615, and 0.610. Higher WTC expressed tolerant to waterlogged condition compared to lower WTC expressed susceptible to waterlogged condition. Those plant were more tolerant compare to BD-6985, JP-00411, JP-03013, JP-14003 and BD-7004 because of the WTC of those plants were 0.568, 0.512, 0.516, 0.531 and 0.554 (Fig. 6). The WTC was expressed tolerance and susceptible capability of a plant under waterlogged condition. Therefore, BD-6998, BD-6985 and BD-7008 believe to more tolerant plant compared to others.

The WTC was expressed tolerance and susceptible capability of a plant under waterlogged condition. Waterlogging tolerance co-efficient (WTC) of root length of genotypes BD-6991, BD-6996, JP-01811 at waterlogging period at 48hours were 0.159, 0.159, 0.153. Higher WTC believe to expressed tolerant to waterlogged condition compared to lower WTC believe to expressed susceptible to waterlogged condition. Those plant were more susceptible compared to GP-83-3 GP-53-1, BD-6959, BARI Til 4 and GP-5 because of the WTC of those plants were 0.169, 0.207, 0.265, 0.178 and 0.241 (Fig. 6). The WTC was expressed tolerance and susceptible capability of a plant under waterlogged condition. Therefore, BD-6991, BD-6996, JP-01811 and GP-83-3 were susceptible genotypes. Survival percentage is an important mean to assess the degree of flood tolerance as reported by Martin *et al*. (2006).

4.1.4. Full length of seedling with waterlogging tolerance co-efficient (WTC) atseedling stage

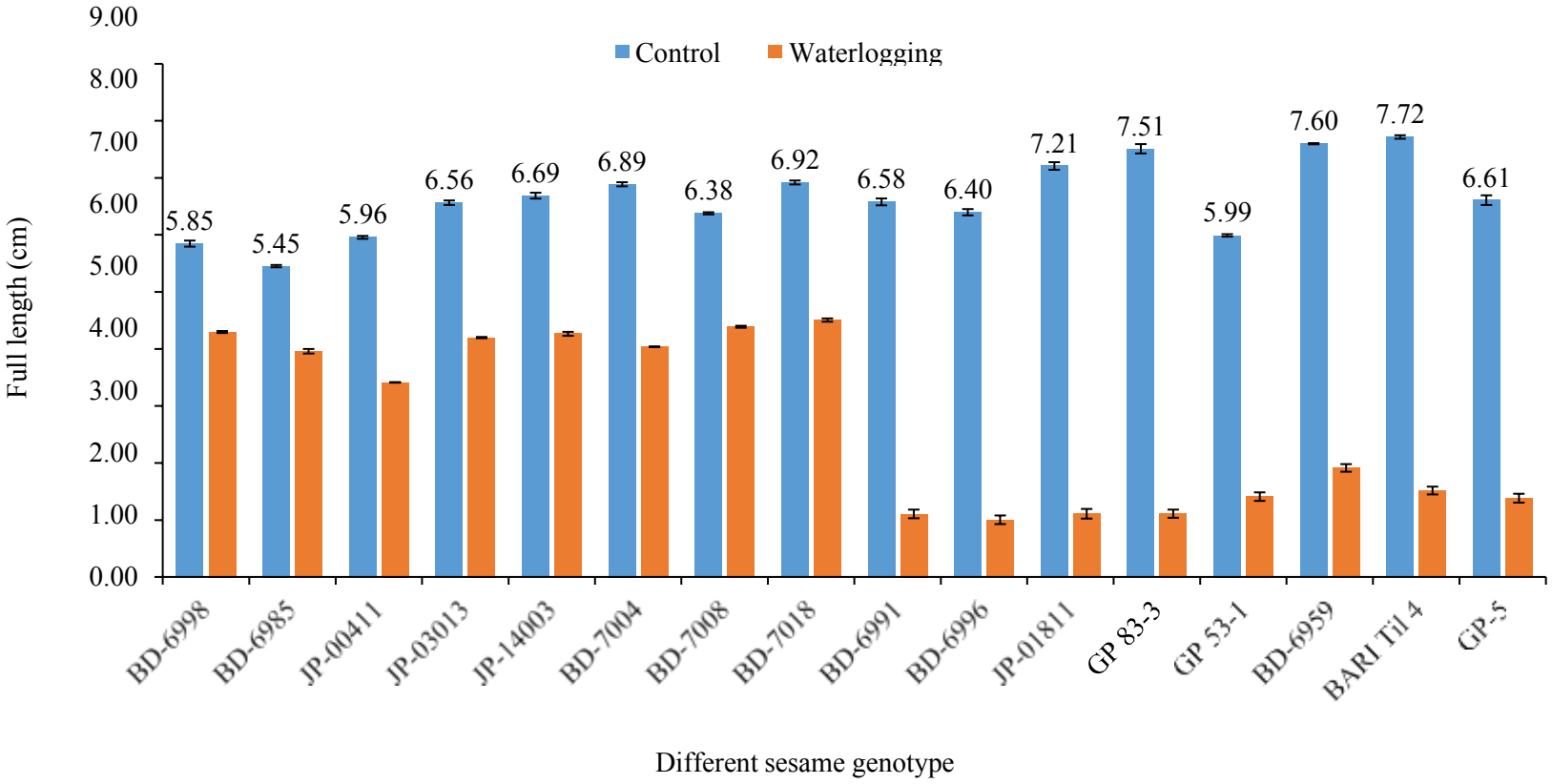

Fig. 7: Full length of seedling of different sesame genotypes under 48 hours waterlogging period. LSD $_{(0.05\%)}$ = 0.0673. (Error bar shown value of standard deviation)

The full length of different sesame genotypes at 48 h (Fig. 7). The results showed that full length of genotypes BD-6991, BD-6996, GP-5 and GP 53-1 at were 6.58 cm, 6.4 cm, 6.61 cm and 5.99 cm at control condition. +These plants were more susceptible compare to GP-83-3, BD-6959, BARI Til 4, JP-01811 and JP-016112 because of the full length of those plants were 7.51 cm, 7.6 cm, 7.72 cm, 7.21cm and 8.01cm at control (Fig.7). Moreover, full length of genotypes BD-6991, BD-6996, GP-5 and GP 53-1 at waterlogging period at 48 h were 1.11cm, 1.0cm, 1.38cm and 1.41cm at waterlogged condition.

Table 10: Percent of inhibition of Length and fresh weight of seedling of different sesame genotypes under waterlogging conducted at 48

Genotype	Length of seedling (cm)		Percent of inhibition at 48 h	Fresh weight of Seedling (gm)		Percent of inhibition at 48 h
	Control	Waterlog up to 48 h		Control	Waterlog up to 48 h	
BD-6998	5.91 j	3.98 f	32.66 n	5.08 j	3.04 b	42.28 m
BD-6985	5.44 k	3.91 g	28.03 p	6.02 b	3.47 a	40.21 o
JP-00411	5.98 i	3.42 h	42.87 i	4.96 k	2.61 e	47.39 h
JP-03013	6.52 g	4.19 d	35.86 k	5.60 f	2.84 d	49.20 j
JP-14003	6.70 f	4.31 c	35.69 l	5.73 e	2.95 c	48.56 k
BD-7004	6.85 e	4.05 e	40.95 j	5.22 h	3.02 b	42.18 i
BD-7008	6.38 h	4.41 b	30.86 o	4.19 l	2.41 f	40.49 no
BD-7018	6.90 e	4.47 a	35.15 m	5.85 d	2.99 c	48.83 l
BD-6991	6.53 g	1.01 m	84.60 d	5.24 h	1.84 g	64.81 c
BD-6996	6.34 h	0.93 mn	85.39 b	6.30 a	1.03 l	83.61 b
JP-01811	7.25 d	1.06 l	87.56 a	5.53 g	1.01 l	86.82 a
GP 83-3	7.42 c	0.92 n	85.33 c	5.11 i	1.18 jk	81.71 b
GP 53-1	5.97 i	1.37 k	77.07 g	5.16 i	1.15 k	77.65 f
BD-6959	7.61 b	1.89 i	75.15 h	5.15 i	1.24 ij	75.94 g
BARI Til 4	7.69 a	1.52 j	80.27 e	5.13 i	1.35 h	73.74 d
GP-5	6.64 g	1.39 k	79.08 f	6.00 c	1.26 i	78.98 e
$LSD_{(0.05\%)}$	0.078	0.05	0.04	0.042	0.03	0.11
CV (%)	0.71	1.13	0.04	0.48	0.92	0.11

These plants were more susceptible compare to GP-83-3, BD-6959, BARI Til 4, JP-01811 and JP-016112 because of the full length of those plants were 1.11cm, 1.99cm, 1.52cm, 1.11cm and 1.42cm at waterlogged condition (Fig.7). Full length of genotypes BD-6998, BD-6985 and JP-00411 at waterlogging period at 48hours were 5.85cm, 5.45cm, and 5.96cm. Those plant were more tolerant compare to BD-7008, JP-03013, JP-14003, BD-7004 and BD-7018 because of the length of those plants were 6.38cm, 6.56cm, 6.69cm, 6.89cm and 6.92cm (Fig. 7; Table 10).

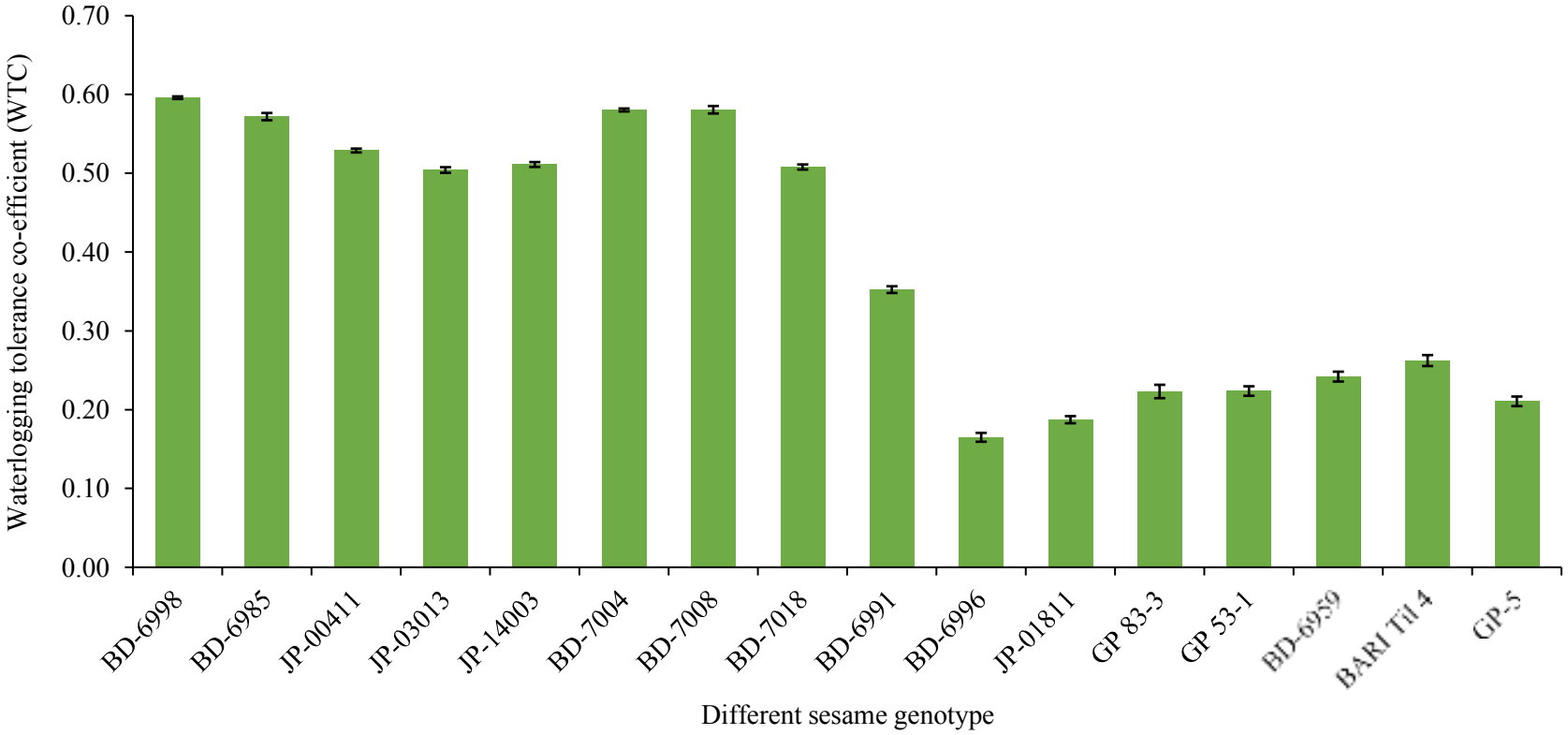

Fig. 8. Waterlogging tolerance co-efficient (WTC) with reference to full length of seedling of different sesame genotypes under 48 hours waterlogging period. LSD $_{(0.05\%)}$ = 0.0115. (Error bar shown value of standard deviation).

The WTC was expressed tolerance and susceptible capability of a plant under waterlogged condition. Waterlogging tolerance co-efficient (WTC) of root length of genotypes BD-6998, BD-6985 and BD-7008 at waterlogging period at 48hours were 0.724, 0.719, and 0.691. Higher WTC expressed tolerant to waterlogged condition compared to lower WTC expressed susceptible to waterlogged condition. Those plant were more tolerant compare to JP-00411, JP-03013, JP-14003, BD-7004 and BD-7018 because of the WTC of those plants were 0.561, 0.641, 0.673, 0.590 and 0.648 (Fig. 8). The WTC was expressed tolerance and susceptible capability of a plant under waterlogged condition. Therefore, BD-6998, BD-6985 and BD-7008 were more tolerant plant compared to others.

The WTC was expressed tolerance and susceptible capability of a plant under waterlogged condition. Waterlogging tolerance co-efficient (WTC) of full length of genotypes BD-6996, JP-01811 and GP 83-3 at waterlogging period at 48hours were 0.146, 0.146, and 0.151. Higher WTC expressed tolerant to waterlogged condition compared to lower WTC expressed susceptible to waterlogged condition. Those plant were more susceptible compare to BD-6991, GP-53-1, BD-6959, BARI Til 4, GP-5 because of the WTC of those plants were 0.175, 0.229, 0.248, 0.197, 0.2 (Fig. 8). The WTC was expressed tolerance and susceptible capability of a plant under waterlogged condition. Therefore, BD-6991, BD-6996, JP-01811 and GP-83-3 were susceptible genotypes. Flooding tolerance varies between crops, varieties, stages of crop, duration of flooding etc. Flooding did not lead to death of seedlings in Arabidopsis (Pigliucci and Kolodynska, 2002).

4.1.5. Full weight with Waterlogging tolerance co-efficient (WTC)

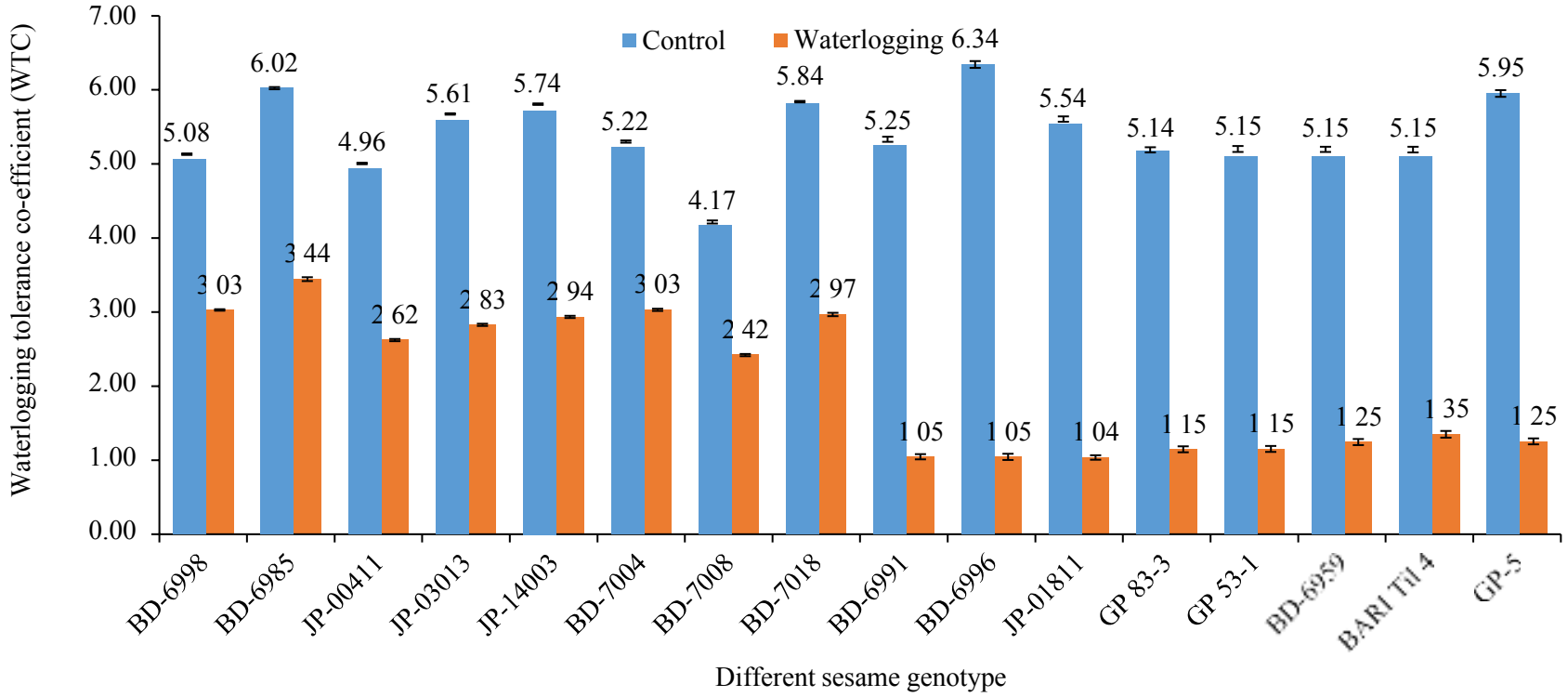

Fig. 9. Full weight of different sesame genotypes under waterlogging condition up to 48 hours at seedling stage. LSD $_{(0.05\%)}$ = 0.0247. (Error bar shown value of standard deviation)

Full weight of genotypes BD-6991, BD-6996, GP-5 and GP 53-1 at waterlogging period at 48hours were 5.25g, 6.34g, 5.95g and 5.15g at control condition. These plants were more susceptible compare to GP-83-3, BD-6959, BARI Til 4, JP-01811 and JP-016112 because of the full weight of those plants were 5.14g, 5.15g, 5.15g, 5.54g and 7.15g at control (Fig.9). Moreover, full weight of genotypes BD-6991, BD-6996, GP-5 and GP 53-1 at waterlogging period at 48hours were 1.85g, 1.05g, 1.25g and 1.15g at waterlogged condition. These plants were more susceptible compare to GP-83-3, BD-6959, BARI Til 4, JP-01811 and JP-016112 because of the full length of those plants were 1.15g, 1.25g, 1.35g, 1.04g and 1.05g at waterlogged condition (Fig.9). Full weight of genotypes BD-6998, BD-6985 and JP-00411 at waterlogging period at 48hours were 5.08g, 6.02g, and 4.96g. Those plant were more tolerant compare to BD-7008, JP-03013, JP-14003, BD-7004 and BD-7018 because of the length of those plants were 4.17g, 5.61g, 5.74g, 5.22g and 5.84 (Fig. 9; Table 10).

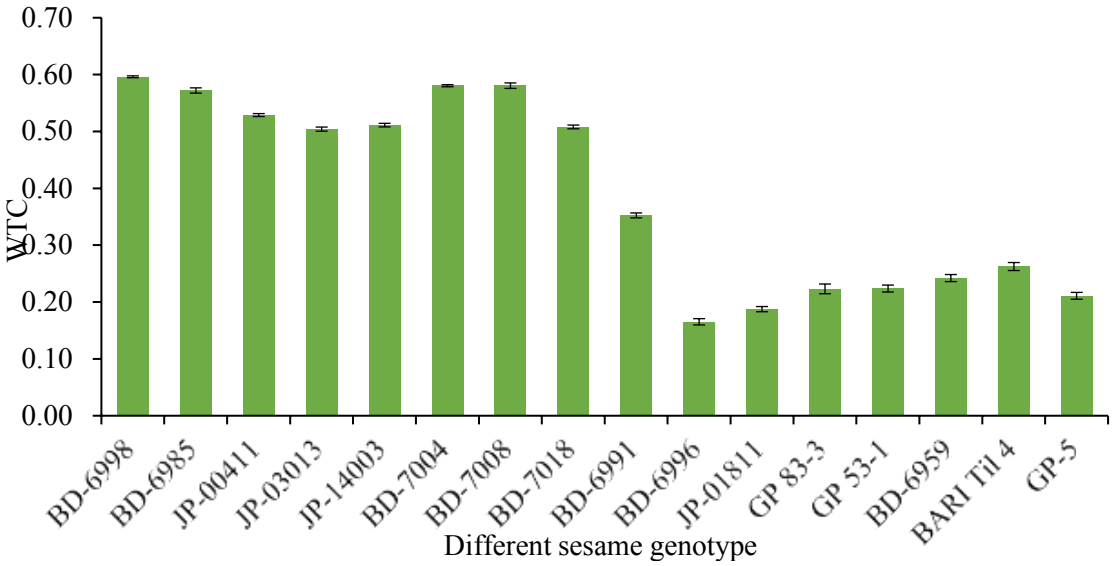

Fig. 10. Waterlogging tolerance co-efficient (WTC) with refer to Full weight of different sesame genotypes under 48 hours waterlogging period. LSD $_{(0.05\%)}$ =5.571E-03. (Error barshown value of standard deviation).

Table 11: Cluster list of waterlogging tolerance of 16 genotype at 48hrs at seedling stage.

Sl No.	Genotype	WTC (SL)	WTC (RL)	WTC (FL)	WTC(FW)	Remark
1	BD-7008	0.76 b	0.62 a	0.69 ab	0.59 a	T
2	BD-6985	0.80 a	0.57 b	0.72 a	0.60 a	T
3	JP-00411	0.60 f	0.51 e	0.56 d	0.53 c	MT
4	JP-03013	0.73 cd	0.52 d	0.64 c	0.51 d	MT
5	JP-14003	0.72 c	0.53 d	0.66 bc	0.51 d	MT
6	BD-7004	0.61 f	0.55 c	0.59 d	0.58 b	MT
7	BD-6998	0.71 d	0.61 a	0.67 b	0.54 b	MT
8	BD-7018	0.67 e	0.61 a	0.65B c	0.51 d	MT
9	BD-6991	0.19 i	0.10 k	0.15 g	0.35 e	MS
10	BD-6996	0.14 j	0.16 j	0.15 g	0.16 h	S
11	JP-01811	014 j	0.15 j	0.15 g	0.18 gh	S
12	GP 83-3	014 j	0.10 k	0.12 h	0.23 fg	S
13	GP 53-1	024 g	0.21 h	0.23 f	0.22 fg	S
14	BD-6959	024 g	0.27 f	0.25 e	0.24 f	S
15	BARI Til 4	0.21 h	0.18 i	0.20 f	0.26 f	S
16	GP-5	0.19 i	0.24 g	0.20 ef	0.21 g	S
	CV (%)	0.018	0.016	0.029	0.0185	
	$LSD_{(0.05)}$	2.47	2.64	4.24	2.85	

N.T(T=tolerant, ST=semi-tolerant, S=susceptible,MS=moderately susceptible).

[WTC SL(Shoot Length) Mean range=0.8-0.7 for T;0.69-0.5 for MT; <0.5 for S

WTC RL(Root Length) Mean range=0.65-0.57 for T;0.56-0.51 for MT; <0.3 for S

WTC FL(Full Length) Mean range=0.72-0.68 for T;0.67-0.56 for MT; <0.2 for S

WTC FW(Full Weight) Mean range=0.6-0.59 for T;0.58-0.51 for MT; <0.25 for S].

The WTC was expressed tolerance and susceptible capability of a plant under waterlogged condition. Waterlogging tolerance co-efficient (WTC) of full weight of genotypes BD-6996, JP-01811 at waterlogging period at 48hours were 0.163, 0.182. Higher WTC expressed tolerant to waterlogged condition compared to lower WTC expressed susceptible to waterlogged condition. Those plant were more susceptible compare to BD-6991, GP 83-3, GP-53-1, BD-6959, BARI Til 4 and GP-5 because of the WTC of those plants were 0.351, 0.231, 0.223, 0.24, 0.262 and 0.21 (Fig.10). The WTC was expressed tolerance and susceptible capability of a plant under waterlogged condition. Therefore, BD-6991, BD-6996, JP-01811 and GP-83-3 were susceptible genotypes. Different degrees of damage is caused in sesame. Sesame is very sensitive to waterlogging as in rapeseed (Zhou *et al*., 2014).

The WTC was expressed tolerance and susceptible capability of a plant under waterlogged condition. Waterlogging tolerance co-efficient (WTC) of root length of genotypes BD-6998, BD-6985 and BD-7004 at waterlogging period at 48hours were 0.597, 0.577, and 0.578. Higher WTC expressed tolerant to waterlogged condition compared to lower WTC expressed susceptible to waterlogged condition. Those plant were more tolerant compare to JP-00411, JP-03013, JP-14003, BD-7008 and BD-7018 because of the WTC of those plants were 0.526, 0.508, 0.514, 0.575 and 0.511 (Fig. 10). Therefore, BD-6998, BD-6985 and BD-7008 were more tolerant plant compared to others.

The WTC was expressed tolerance and susceptible capability of a plant under waterlogged condition. The survival percentage of sesame genotypes was 40 under waterlogged condition. Duration of flooding also affected the seedling survival percentage. All the thirty genotypes survived 12 h and 24 h of waterlogging and only sixteen genotypes survived 48

h of waterlogging. Sarkar *et al*. (2016) also reported that duration of waterlogging can reduce crop growth in sesame.

The WTC was expressed tolerance and susceptible capability of a plant under waterlogged condition. Therefore, BD-6998, BD-6985, JP-14003 and BD-7008 were more tolerant plant compared to others whereas BD-6996 and JP-01811 were susceptible genotypes (table 12).

Experiment 2. Morphology, yield and yield contributing characters of different sesame genotypes under waterlogging condition

From earlier experiment, we found that sesame genotypes of BD-6998, BD-6985, BD-7008 and JP-14003 showed better performance and survivability compare to others where BD-6996 and JP-01811 which found more susceptible compare to others. These 10 (ten) genotypes were considered as planting a pot experiment at Physiology Department of Bangladesh Agriculture Research Institute (BARI) during *Rabi* season from 2017-2018. Waterlogging was imposed in different DAS (Days after Sowing) in the pot. Duration of waterlogging was 48 hours and water level were maintained 2 cm above soil surface by replenishing frequently. After the treatment period, pot was replaced for water tank and plants were allowed to grow up to maturity.

The analysis of variance revealed that the genotypes recorded highly significant differences at different waterlogging condition with reference to morphological data like plant height, number of leaves plant^{1}, number of branches plant^{1}, shoot fresh weight of (g), shoot dry weight of (g), root fresh weight of (g), root dry weight of (g), root length and root shoot ratio. Yield contributing data were data of 1st flowering, data of 50% flowering, data of 1st fruit set, data of maturity, number of pod plant, number of seed per plant, thousand seed weight and Yield.

4.2.1. Plant Height

Different sesame genotypes showed statistically significant differences on plant height (Table 13, Appendix 4). BD-6985 recorded the highest height (98.66 cm) which was significant with other varieties. However, the lowest height (66.08 cm) was observed from BD-6991 genotype. This data highlighted that sesame plant are more sensitive to waterlogging and BD-6985 showed more capable to increase plant height compared to BD-6991. The other different eight genotypes showed various values of plant height. It was reported that the various genotypes of similar species of cultivated crops showed different plant architecture including plant length. Genetic information of a crop plants have dominant roles to a variety of crops either dwarf ar tall. It also reported that plant

height and length usually linked with biosynthesis of plant hormone including IAA, GA, Cytokinin, ABA etc. Therefore, all together these data suggest that BD-6985 is the tallest genotypes than othergenotypes of sesame of this study.

The plant height of sesame genotypes at harvest showed significant variation to waterlogging stress at different age of the plants (Table 12, Appendix 4). The lowest plant height (74.20cm) was found under waterlogging stress which imposed to different sesame plant at the age of 50 d whereas the highest plant height (86.83 cm) was found from control/ withoutexcess water stress. The plant height of sesame showed lower reduction at the age of 40 d than the age of 30 d of waterlogging stress. These results indicate that the rate of reduction of plant height are variable to waterlogging at different age of the plant.

The interaction effects of sesame genotypes and waterlogging at different age of the plant showed significant variations on plant height of sesame (Table 14, Appendix 4). In this study, ten different genotypes were used which were taken from experiment 1 and waterlogging wasimposed at different age of the plant. The plant height was recorded in all treatment combination to waterlogging stress in all genotypes compared to control treatment combination. The highest plant height (104.47 cm) was found from the treatment combination of BD-6985 and control. The plant height was declined to waterlogging at different age of the plant in all aspect. The rate of the reduction of plant height were almost similar trend to waterlogging at different age of the plant. In all genotypes plant height reduction were much higher under waterlogging stress; vegetative stage (30 d) andreproductive stage (50d age of the plant) than the early reproductive stage (40 d age of the plant). These results also highlighted that sesame plants have more capacity to enhance plant height at early reproductive stage (40 d age of the plant) than vegetative and reproductive period under waterlogging stress. The lowest plant height (61.00 cm) was recorded from the treatment combination of JP-01811 and waterlogging at 50 d age of theplant; followed by genotypes BD-6991 and waterlogging at 50 d age of the plant treatmentcombination. Therefore, these results suggest that plant height decrease under waterloggingcondition in different sesame genotypes.

The percentage of plant height reduction was average 25%. Plant height was reduced by waterlogging in all the genotypes under study which was in conformity with the findings

of Hossain and Salahuddin (2001) in sesame. The reduction in plant height may be due to the energy conservation for maintenance and survival. Among *Sesamum indicum* genotypes, highest plant height was recorded by Ayali and lowest by SV 2 (V. Athul. 2016).

Table 12: Effect of different sesame genotypes on plant length, number of leaves, number of branches and root length at harvest.

Genotypes	Plant height(cm)	No. of leaves/Plant	No. of branches/plant	Root length(cm)
BD 7008	93.25 b	20.91 b	8.50 ab	9.65 a
BD-6985	98.66 a	23.66 a	8.91 a	9.65 a
BD-6998	89.91 c	20.50 b	8.25 bc	8.29 b
JP-00411	84.03 de	20.50 b	7.83 cd	8.11 bc
JP-03013	85.41 d	20.83 b	8.41 abc	8.06 c
JP-14003	83.41 e	21.16 b	8.08 bc	7.43 e
JP 01811	68.33 f	18.41 c	6.91 de	7.65 d
BD-6996	70.75 g	18.33 c	7.25 e	8.01 c
BD-6991	66.08 h	18.33 c	7.25 de	6.52 f
GP 83-3	69.08 g	18.16 c	7.25 de	6.53 f
CV (%)	2.20	4.96	9.49	3.30
$LSD_{(0.05\%)}$	1.44	0.81	0.60	0.21

Values followed by same letters are not significantly different from each other by LSD at 5% level for each other.

Table 13: Effect of waterlogging at different age of the plant on plant height, number of leaves, and number of branches and root length of different sesame genotypes at harvest.

Age of plant	Plant height(cm)	No. of leaves/Plant	No. of branches/plant	Root length(cm)
Control	86.83 a	23.26 a	9.93 a	9.16 a
30 d	79.33 c	19.36 c	6.96 c	7.47 c
40 d	83.23 b	20.90 b	8.40 b	8.37 b
50 d	74.20 d	16.80 d	6.16 d	6.95 d
CV (%)	2.20	4.96	9.49	3.30
$LSD_{(0.05\%)}$	0.91	0.51	0.38	0.13

Values followed by same letters are not significantly different from each other by LSD at 5% level for each other.

Table 14: Interaction effect of genotype and waterlogging at different age of the plant on plant height, number of leaves, number of branches and root length of sesame.

Genotypes X Age of plants (Interaction)		Plant height(cm)	No. of leaves/Plant	No. of branches/plant	Root length(cm)
BD 7008	Control	97.00 b	24.33 bc	11.00 ab	11.28 b
	30 d	90.67 df	20.00 fh	7.33 ik	9.15 de
	40 d	95.33 b	21.66 e	9.33 dg	9.64 c
	50 d	90.00 df	17.66 km	6.33 km	8.52 f
BD-6985	Control	104.67 a	28.00 a	11.66 a	11.98 a
	30 d	96.67 b	22.33 de	7.66 hj	9.00 e
	40 d	102.00 a	25.33 b	9.66 cf	9.47 cd
	50 d	91.33 de	19.00 hk	6.66 jl	8.14 f
BD-6998	Control	95.00 bc	23.33 cd	10.66 ac	9.37 ce
	30 d	88.00 fg	20.00 fh	7.00 jk	8.14 f
	40 d	92.33 cd	21.33 ef	8.66 fh	8.95 e
	50 d	84.33 hi	17.33 lm	6.66 jl	6.72 ik
JP-00411	Control	91.33 de	23.33 cd	10.00 be	9.15 de
	30 d	86.00 gh	19.33 hj	6.66 jl	9.64 c
	40 d	88.67 eg	21.66 e	8.33 ik	6.83 hj
	50 d	70.33 op	17.66 km	6.33 km	6.81 hj
JP-03013	Control	90.33 df	24.00 bc	10.33 bd	9.00 e
	30 d	82.33 ij	19.66 gi	7.33 ik	9.47 cd
	40 d	88.00 fg	21.66 e	9.00 eg	6.80 hk
	50 d	81.00 jk	18.00 jm	7.00 jk	6.97 hj
JP-14003	Control	91.00 de	24.66 bc	9.66 cf	8.14 f
	30 d	81.67 ij	21.00 eg	7.33 ik	8.95 e
	40 d	86.33 gh	22.00 de	9.00 eg	6.37 km
	50 d	74.67 mn	17.00 mn	6.33 km	6.25 lm
JP 01811	Control	78.67 kl	21.00 eg	9.33 dg	9.19 de
	30 d	69.00 pr	18.33 im	6.66 jl	7.66 g
	40 d	74.33 n	19.00 hk	7.33 ik	7.17 h
	50 d	61.00 u	15.00 o	5.66 lm	7.58 jl
BD-6996	Control	72.33 no	21.33 ef	8.66 fh	9.17 de
	30 d	67.33 qs	18.00 jm	6.33 km	9.04 de
	40 d	69.00 pr	18.66 hl	7.33 ik	7.13 hi
	50 d	64.67 st	15.66 no	5.33 m	6.70 jk
BD-6991	Control	70.67 op	21.00 eg	9.00 eg	7.13 hi
	30 d	64.67 st	17.66km	6.66 jl	6.11 m
	40 d	66.67 rs	19.33 hj	7.66 hj	6.15 m
	50 d	62.33 tu	15.33 o	5.66 lm	6.70 jk
GP 83-3	Control	77.33 lm	21.66 e	9.00 eg	7.17 h
	30 d	67.00 qs	17.33 lm	6.66 jl	6.58 jl
	40 d	69.67 oq	18.33 im	7.66 hj	6.24 lm
	50 d	62.33 tu	15.33 o	5.66 lm	6.12 m
CV (%)		2.20	4.96	9.49	3.30
$LSD_{(0.05\%)}$		2.89	1.62	1.21	0.42

Values followed by same letters are not significantly different from each other by LSD at 5% level for each other.

4.2.2. Number of leaves plant^{-1}

Statistically significant differences were observed in different sesame genotypes on number of leaves (Table 13, Appendix 5). BD-6985 recorded the highest number of leaves (23.66) which was significant with other varieties. However, the lowest height (18.16) wasobserved from GP 83-3 genotype. This data highlighted that sesame plant are more sensitive to waterlogging and BD-6985 showed more capable to increase number of leavescompared to GP 83-3. The other different eight genotypes showed various values of number of leaves. It was reported that the various genotypes of similar species of cultivated crops showed different plant architecture including number of leaves. Genetic information of a crop plants have dominant roles to a variety of crops on number of leaves. It also reported that plant leaves are usually linked with biosynthesis of plant hormone including IAA, GA, Cytokinin, ABA etc. Therefore, all together these data suggest that BD-6985 possessed highest number of leaves than other genotypes of sesame of this study.

The number of leaves of different genotypes at harvest showed significant variation to waterlogging stress at different age of the plants (Table 12, Appendix 5). The lowest number of leaves (16.80) was found under waterlogging stress which imposed to different sesame plant at the age of 50 d whereas the highest number of leaves (23.26) was found from control. Thenumber of leaves showed lower reduction at the age of 40 d than the age of 30 d of waterlogging stress. These results indicate that the rate of reduction of the number of leaves are variable to waterlogging at different age of the plant.

The interaction effects of sesame genotypes and waterlogging at different age of the plant showed significant variations on number of leaves of sesame (Table 14, Appendix 5). In this study, ten different genotypes were used which were taken from experiment 1 and waterlogging was imposed at different age of the plant. The number of leaves was recorded in all treatment combination to waterlogging stress in all genotypes compared to control treatment combination. The highest number of leaves (28.00) was found from the treatment combination of BD-6985 and control. The number of leaves was declined to

waterloggingat different age of the plant in all aspect. The rate of the reduction of number of leaves were almost similar trend to waterlogging at different age of the plant. In all genotypes number of leaves reduction were much higher under waterlogging stress; vegetative stage (30 d) and reproductive stage (50d age of the plant) than the early reproductive stage (40 d age ofthe plant). These results also highlighted that sesame plants have more capacity to enhancenumber of leaves at early reproductive stage (40 d age of the plant) than vegetative and reproductive period under waterlogging stress. The lowest number of leaves (15.00) was recorded from the treatment combination of JP-01811 and waterlogging at 50 d age of theplant; followed by genotypes BD-6991 and waterlogging at 50 d age of the plant treatmentcombination. Therefore, these results suggest number of leaves decrease underwaterlogging condition in different sesame genotypes.

4.2.3. Number of branches plant^{-1}

Statistically significant differences were observed in different sesame genotypes on number of branches per plant (Table 13, Appendix 6). BD-6985 recorded the highest number of branches per plant (8.91) which was significant with other varieties. However, the lowest height (7.25) was observed from BD-6991 genotype. This data highlighted that sesame plant are more sensitive to waterlogging and BD-6985 showed more capable to increase number of branches per plant compared to BD-6985. The other different eight genotypes showed various values of number of branches. It was reported that the various genotypes of similar species of cultivated crops showed different plant architecture including number of branches. Genetic information of a crop plants have dominant roles to a variety of crops on number of branches. It also reported that plant branches are usually linked with biosynthesis of plant hormone including IAA, GA, Cytokinine, ABA etc. Therefore, all together these data suggest that BD-6985 possessed highest number of branches than other genotypes of sesame of this study.

The number of branches of different genotypes at harvest showed significant variation to waterlogging stress at different age of the plants (Table 12, Appendix 6). The lowest number of leaves (6.16) was found under waterlogging stress which imposed to different sesame plant at theage of 50 d whereas the highest number of branches (9.96) was found from control. The number of leaves showed lower reduction at the age of 40 d than the age of 30 d of waterlogging stress. These results indicate that the rate of reduction of the

number of branches are variable to waterlogging at different age of the plant.

The interaction effects of sesame genotypes and waterlogging at different age of the plant showed significant variations on number of branches of sesame (Table 14, Appendix 6). In this study, ten different genotypes were used which were taken from experiment 1 and waterlogging was imposed at different age of the plant. The number of branches was recorded in all treatment combination to waterlogging stress in all genotypes compared to control treatment combination. The highest number of branches (11.66) was found from the treatment combination of BD-6985 and control. The number of branches was declined to waterlogging at different age of the plant in all aspect. The rate of the reduction of number of branches were almost similar trend to waterlogging at different age of the plant. In all genotypes number of branches reduction were much higher under waterlogging stress; vegetative stage (30 d) and reproductive stage (50d age of the plant) than the early reproductive stage (40 d age of the plant). These results also highlighted that sesame plants have more capacity to enhance number of branches at early reproductive stage (40 d age of the plant) than vegetative and reproductive period under waterlogging stress. The lowest number of branches (5.33) was recorded from the treatment combination of BD-6996 and waterlogging at 50 d age of the plant; followed by genotypes JP-01811 (5.66) and waterlogging at 50 d age of the plant treatment combination. Therefore, these results

suggest number of branches decrease under waterlogging condition in different sesame genotypes.

Control plant recorded higher plant branch than treatments. Number of primary branches plant^{-1} is important yield contributing characters. *Sesamum indicum* genotypes highest values for this character was recorded by Ayali and lowest by SV 2. The wild species *Sesamumm alabaricum* recorded a lower value than that of SV 2 (V. Athul. 2016). Waterlogged condition reduced the number of primary branches plant^{-1}. Similar results were reported by Ghoi *et al.* (1996) and Gutierrez *et al.* (1996).

4.2.4. Root length

Statistically significant differences were observed in different sesame genotypes on root length of plant (Table 13, Appendix 9). BD-6985 and BD-7008 recorded the highest root length (9.65 cm) which was significant with other varieties. However, the lowest root length (6.52 cm)was observed from BD-6991 genotype. This data highlighted that sesame plant are more sensitive to waterlogging and BD-6985 and BD-7008 showed more capable to increase root length compared to BD-6985. The other different eight genotypes showed various values of root length. It was reported that the various genotypes of similar species of cultivated crops showed different plant architecture including root length. Genetic information of a crop plants have dominant roles to a variety of crops on root length. It alsoreported that root length of plant is usually linked with biosynthesis of plant hormone including IAA, GA, Cytokinine, ABA etc. Therefore, all together these data suggest that BD-6985 possessed highest root length than other genotypes of sesame of this study.

The root length of different genotypes at harvest showed significant variation to waterlogging stress at different age of the plants (Table 12, Appendix 9). The lowest root length (6.95 cm) was found under waterlogging stress which imposed to different sesame plant at the age of 50 d whereas the highest number of branches (9.16 cm) was found from control. The root length showed lower reduction at the age of 40 d than the age of 30 d of waterlogging stress. These results indicate that the rate of reduction of the root length are variable to waterlogging at different age of the plant.

The interaction effects of sesame genotypes and waterlogging at different age of the plant showed significant variations on root length of sesame (Table 14, Appendix 9). In this study, ten different genotypes were used which were taken from experiment 1 and waterlogging was imposed at different age of the plant. The root length was recorded in all treatment combination to waterlogging stress in all genotypes compared to control treatment combination. The highest root length (11.98 cm) was found from the treatment combination of BD-6985 and control. The root length was declined to waterlogging at different age of the plant in all aspect. The rate of the reduction of root length were almost similar trend to waterlogging at different age of the plant. In all genotypes root length reduction were much higher under waterlogging stress; vegetative stage (30 d) and reproductive stage (50d age of the plant) than the early reproductive stage (40 d age of the plant). These results also highlighted that sesame plants have more capacity to enhance root length at early reproductive stage (40 d age of the plant) than vegetative and reproductive period under waterlogging stress. The lowest root length (6.11 cm) was recorded from the treatment combination of BD-6991 and waterlogging at 50 d age of the plant; followed by genotypes GP 83-3 (6.12 cm) and waterlogging at 50 d age of the plant treatment combination. Therefore, these results root length decrease under waterlogging condition in different sesame genotypes.

Among the *Sesamum indicum* genotypes root length was highest for Ayali (12.2 cm) and it was Thilak and root length was lowest for SV 2 (7.30 cm) (V. Athul. 2016). Wild species *Sesamum malabaricum* had lowest root length (6.4 cm) (V. Athul. 2016). Five genotypes recorded higher value than general mean (9.36 cm) and root length was more for control plants (V. Athul. 2016). The root length was decreased under waterlogging condition in all the genotypes which was in confirmatory with the findings of Zhang *et al*. (2015).

Plate 3: The root architecture of four sesame plant with two tolerant (BD-7008 and BD-6985) and two susceptible (BD-6996 and JP-01811).

4.2.5. Shoot fresh weight

Statistically significant differences were observed in different sesame genotypes on shoot fresh weight (Table 15, Appendix 7). BD-6985 recorded the highest shoot fresh weight (20.54 g) which was significant with other varieties. However, the lowest shoot fresh weight (16.41) was observed from JP-03013 genotype. This data highlighted that sesame plant are more sensitive to waterlogging and BD-6985 showed more capable to increase shoot fresh weight to JP-03013. The other different eight genotypes showed various values of shoot fresh weight. It was reported that the various genotypes of similar species of cultivated crops showed different plant architecture including shoot fresh weight. Genetic information of a crop plants have dominant roles to a variety of crops on shoot fresh weight. Therefore, all together these data suggest that BD-6985 possessed highest shoot fresh weight than other genotypes of sesame of this study.

The shoot fresh weight of different genotypes at harvest showed significant variation to waterlogging stress at different age of the plants (Table 16, Appendix 7). The lowest shoot fresh weight (15.58 g) was found under waterlogging stress which imposed to different sesame plant at the age of 50 d whereas the highest shoot fresh weight (21.56) was found from control. The shoot fresh weight showed lower reduction at the age of 40 d than the age of 30 d of

waterlogging stress. These results indicate that the rate of reduction of shoot fresh weight are variable to waterlogging at different age of the plant.

The interaction effects of sesame genotypes and waterlogging at different age of the plant showed significant variations on shoot fresh weight of sesame (Table 17, Appendix 7). In this study, ten different genotypes were used which were taken from experiment 1 and waterlogging was imposed at different age of the plant. The shoot fresh weight was recorded in all treatmentcombination to waterlogging stress in all genotypes compared to control treatment combination. The highest shoot fresh weight (24.30 g) was found from the treatment combination of BD-6985 and control. The shoot fresh weight was declined to waterloggingat different age of the plant in all aspect. The rate of the reduction of shoot fresh weight were almost similar trend to waterlogging at different age of the plant. In all genotypes shoot fresh weight reduction were much higher under waterlogging stress; vegetative stage (30 d) and reproductive stage (50 d age of the plant) than the early reproductive stage (40 d age of the plant). These results also highlighted that sesame plants have more capacity to enhance shoot fresh weight at early reproductive stage (40 d age of the plant) than vegetative and reproductive period under waterlogging stress. The lowest shoot fresh weight (14.40 g) was recorded from the treatment combination of JP-01811 and waterlogging at 50 d age of the plant; followed by genotypes BD-6996 (14.80) and waterlogging at 50 d age of the plant treatment combination. Therefore, these results shootfresh weight decrease under waterlogging condition in different sesame genotypes.

Table 15: Effect of waterlogged treatments on shoot fresh weight, shoot dry weight, and root fresh weight, root dry weight of different sesame genotypes under differentvariety.

Genotypes	Shoot fresh weight(g)	Shoot dry weight(g)	Root fresh weight(g)	Root dry weight(g)
BD 7008	20.01 a	2.65 b	3.55 a	0.71 b
BD-6985	20.54 a	2.85 a	3.00 c	0.79 a
BD-6998	18.19 bcd	2.69 ab	2.77 d	0.61 c
JP-00411	18.42 bc	2.65 b	3.25 b	0.53 d
JP-03013	16.41 bc	2.61 bc	2.65 e	0.62 c
JP-14003	18.50 b	2.71 ab	2.56 ef	0.61 c
JP 01811	17.47 e	2.45 d	2.51 fg	0.60 cd
BD-6996	16.98 de	2.39 cd	2.49 fg	0.58 c
BD-6991	17.75 cd	2.44 cd	2.46 g	0.55 d
GP 83-3	17.70 cde	2.61 bc	2.33 h	0.61 c
CV (%)	4.95	8.67	4.02	9.68
$LSD_{(0.05\%)}$	0.74	0.18	0.09	0.04

Values followed by same letters are not significantly different from each other by LSD at 5% level for each other.

Table 16: Effect of waterlogged treatments on shoot fresh weight, shoot dry weight, and root fresh weight, root dry weight of different sesame genotypes under differentsowing time.

Age of plant	Shoot fresh weight(g)	Shoot dry weight(g)	Root fresh weight(g)	Root dry weight(g)
Control	21.56 a	2.95 a	3.06 a	0.74 a
30D	17.38 c	2.43 c	2.64 c	0.60 b
40D	19.07 b	2.62 b	2.86 b	0.61 b
50D	15.58 d	2.42 c	2.49 d	0.54 c
CV (%)	4.95	8.67	4.02	9.68
$LSD_{(0.05\%)}$	0.46	0.11	0.05	0.03

Values followed by same letters are not significantly different from each other by LSD at 5% level for each other.

Effect of waterlogged treatments on shoot fresh weight of different sesame genotypes under different variety have been presented in (Table 16, Appendix 7). Different varieties showed statistically significant differences on shoot fresh weight. BD-6985 recorded the highest weight (20.54 g) followed by BD-7008 (20.01). However, which was statistically significant at with other varieties. The lowest weight (16.98 g) was observed from JP-01811 followed by (17.47 g) was observed from BD-6996. Control plant recorded higher fresh

weight than treatments. The percentage of shoot fresh weight reduction was average 40% under water logged condition compare to control treatment.

Shoot fresh weight significantly differed among all the genotypes with variety (Appendix 7). Among *Sesamum indicum* genotypes, highest fresh weight was recorded by BD-6985 (24.3 g) at control condition followed by BD-7008 (23.40 g) at control condition. Control plant recorded higher fresh weight than treatments. The percentage of shoot fresh weight reduction was average 40% under water logged condition compare to control treatment. Whereas lowest weight was recorded for JP 01811 (14.40 g) at 50 d followed by BD-6996(14.80 g) at 50 d (Table 17, Appendix 7).

Table 17: Interaction effect of genotype and waterlogging at different age of the plant on shoot fresh weight, shoot dry weight, and root fresh weight, root dry weightof different sesame genotypes.

Genotypes X Age of plants (Interaction)		Shoot fresh weight(g)	Shoot dry weight(g)	Root fresh weight(g)	Root dry weight(g)
BD 7008	Control	23.40 ab	3.18 ab	3.80 a	0.81 bc
	30 d	18.50 hk	2.33 h-k	3.75 a	0.71 d-h
	40 d	21.40 ce	2.77 d-g	3.46 b	0.877 cde
	50 d	16.76 l-p	2.32 ijk	3.18 c	0.56 klm
BD-6985	Control	24.30 a	3.49 a	3.49 b	0.93 a
	30 d	18.83 gj	2.55 f-k	3.06 cd	0.74 c-g
	40 d	21.93 bd	2.81 c-f	2.90 de	0.80 bcd
	50 d	17.10 km	2.54 f-k	2.53 hij	0.69 e-j
BD-6998	Control	21.93 bd	3.13 a-d	3.13 c	0.75 c-f
	30 d	17.00 lm	2.57 f-k	2.73 efg	0,59 jkl
	40 d	18.83 gj	2.60 f-j	2.66 fgh	0.65 g-k
	50 d	15.00 qr	2.49 f-k	2.56 ghi	0.46 n
JP-00411	Control	21.53 ce	3.17 abc	3.75 a	0.70 e-i
	30 d	17.46 jm	2.40 g-k	3.46 b	0.50 lmn
	40 d	19.26 fh	2.69 efgh	3.04 cd	0.46 n
	50 d	15.43 or	2.32 ijk	3.04 cd	0.48 mn
JP-03013	Control	22.06 bc	2.97 bcde	3.06 cd	0.88 ab
	30 d	17.20 km	2.50 f-k	2.90 de	0.66 f-k
	40 d	19.03 fi	2.60 f-j	2.31 k	0.48 mn
	50 d	15.36 or	2.39 h-k	2.33 k	0.48 mn
JP-14003	Control	22.13 bc	3.07 bcd	2.73 efg	0.68 e-j
	30 d	17.26 km	2.45 f-k	2.66 fgh	0.47 mn
	40 d	19.10 fi	2.69 e-i	2.53 hij	0.65 g-k
	50 d	15.50 n-r	2.64 f-j	2.33 k	0.65 g-k
JP 01811	Control	19.03 fi	2.64 e-j	2.64 f-h	0.64 h-k
	30 d	16.93 ln	2.20 k	2.61 f-i	0.61 i-k
	40 d	17.46 j-m	2.42 g-k	2.44 i-k	0.51 l-n
	50 d	14.40 r	2.31 jk	2.27 kl	0.56 k-m
BD-6996	Control	20.50 def	2.69 e-h	2.75 ef	0.65 g-k
	30 d	16.83 l-o	2.35 h-k	2.54 h-j	0.64 h-k
	40 d	17.76 i-l	2.44 g-k	2.44 i-k	0.61 i-k
	50 d	14.80 qr	2.32 jk	2.33 k	0.51 l-n
BD-6991	Control	20.26 eg	2.32 ik	2.65 f-h	0.61 i-k
	30 d	16.63 l-p	2.33 hk	2.65 f-h	0.51 l-n
	40 d	18.10 h-l	2.77 dg	2.28 kl	0.51 l-n
	50 d	16.00 m-q	2.32 ik	2.27 kl	0.56 k-m
GP 83-3	Control	20.46 d-f	2.81 c-f	2.57 f-i	0.77 c-e
	30 d	17.16 km	2.54 f-k	2.26 kl	0.56 k-m
	40 d	17.86 h-l	2.40 g-k	2.36 jk	0.65 g-k
	50 d	15.33 pq	2.69 e-h	2.11 l	0.47 mn
CV (%)		4.95	8.67	4.02	9.68
$LSD_{(0.05\%)}$		1.48	0.36	0.18	0.09

Values followed by same letters are not significantly different from each other by LSD at

5% level for each other.

4.2.6 Shoot dry weight

Statistically significant differences were observed in different sesame genotypes on shoot dry weight (Table 15, Appendix 8). BD-6985 recorded the highest shoot fresh weight (20.85 g) which was significant with other varieties. However, the lowest shoot dry weight (2.39 g) was observed from BD-6996 genotype. This data highlighted that sesame plant are more sensitive to waterlogging and BD-6985 showed more capable to increase shoot dry weightto BD-6996. The other different eight genotypes showed various values of shoot dry weight. It was reported that the various genotypes of similar species of cultivated crops showed different plant architecture including shoot dry weight. Genetic information of a crop plants have dominant roles to a variety of crops on dry fresh weight. Therefore, all together these data suggest that BD-6985 possessed highest dry fresh weight than other genotypes of sesame of this study.

The shoot dry weight of different genotypes at harvest showed significant variation to waterlogging stress at different age of the plants (Table 16, Appendix 8). The lowest shoot dry weight(2.42 g) was found under waterlogging stress which imposed to different sesame plant at the age of 50 d whereas the highest shoot dry weight (2.95 g) was found from control. The shoot dry weight showed lower reduction at the age of 40 d than the age of 30 d of waterlogging stress. These results indicate that the rate of reduction of shoot dry weight are variable to waterlogging at different age of the plant.

The interaction effects of sesame genotypes and waterlogging at different age of the plant showed significant variations on shoot dry weight of sesame (Table 17, Appendix 8). In this study, ten different genotypes were used which were taken from experiment 1 and waterlogging wasimposed at different age of the plant. The dry fresh weight was recorded in all treatment combination to waterlogging stress in all genotypes compared to control treatment combination. The highest shoot dry weight (3.49g) was found from the treatment combination of BD-6985 and control. The shoot dry weight was declined to waterloggingat different age of the plant in all aspect. The rate of the reduction of shoot dry weight werealmost similar trend to waterlogging at different age of the plant. In all genotypes shoot dry weight reduction were much higher under waterlogging stress;

vegetative stage (30 d) and reproductive stage (50 d age of the plant) than the early reproductive stage (40 d age of the plant). These results also highlighted that sesame plants have more capacity to enhance shoot dry weight at early reproductive stage (40 d age of the plant) than vegetative and reproductive period under waterlogging stress. The lowest shoot dry weight (2.20 g) was recorded from the treatment combination of JP-01811 and waterlogging at 50 d age of theplant; followed by genotypes BD-6996 (2.32 g) and waterlogging at 50 d age of the plant treatment combination. Therefore, these results shoot dry weight decrease under waterlogging condition in different sesame genotypes.

4.2.7. Root fresh weight

Statistically significant differences were observed in different sesame genotypes on root fresh weight (Table 15, Appendix 7). BD-7008 recorded the highest root fresh weight (3.55 g) which was significant with other varieties. However, the lowest shoot dry weight (2.33 g) was observed from GP 83-3 genotype. This data highlighted that sesame plant are more sensitive to waterlogging and BD-7008 showed more capable to increase root fresh weightto GP 83-3. The other different eight genotypes showed various values of root fresh weight. It was reported that the various genotypes of similar species of cultivated crops showed different plant architecture including root fresh weight. Genetic information of a crop plants have dominant roles to a variety of crops on root fresh weight. Therefore, all together these data suggest that BD-7008 possessed highest root fresh weight than other genotypesof sesame of this study.

The root fresh weight of different genotypes at harvest showed significant variation to waterlogging stress at different age of the plants (Table 16, Appendix 7). The lowest root fresh weight (2.49g) was found under waterlogging stress which imposed to different sesame plant at the age of 50 d whereas the highest root fresh weight (3.06g) was found from control. Theroot fresh weight showed lower reduction at the age of 40 d than the age of 30 d of waterlogging stress. These results indicate that the rate of reduction of root fresh weight are variable to waterlogging at different age of the plant.

The interaction effects of sesame genotypes and waterlogging at different age of the plant showed significant variations on root fresh weight of sesame (Table 17, Appendix 7). In this study, ten different genotypes were used which were taken from experiment 1 and waterlogging was imposed at different age of the plant. The root fresh weight was

recorded in all treatment combination to waterlogging stress in all genotypes compared to control treatment combination. The highest root fresh weight (3.80g) was found from the treatment combination of BD-7008 and control. The root fresh weight was declined to waterlogging at different age of the plant in all aspect. The rate of the reduction of root fresh weight were almost similar trend to waterlogging at different age of the plant. In all genotypes root fresh weight reduction were much higher under waterlogging stress; vegetative stage (30 d) and reproductive stage (50d age of the plant) than the early reproductive stage (40 d age of the plant). These results also highlighted that sesame plants have more capacity to enhance root fresh weight at early reproductive stage (40 d age of the plant) than vegetative and reproductive period under waterlogging stress. The lowest root fresh weight (2.11 g) was recorded from the treatment combination of GP 83-31 and waterlogging at 50 d age of the plant; followed by genotypes BD-6991 (2.27 g) and waterlogging at 50 d age of the plant treatment combination. Therefore, these results root fresh weight decrease under waterlogging condition in different sesame genotypes.

4.2.8. Root Dry weight

Statistically significant differences were observed in different sesame genotypes on root dry weight (Table 15, Appendix 11). BD-6985 recorded the highest root fresh weight (0.79 g) which was significant with other varieties. However, the lowest root dry weight (0.53 g) was observed from JP-00411 genotype. This data highlighted that sesame plant are more sensitive to waterlogging and BD-6985 showed more capable to increase root fresh weight to JP- 00411. The other different eight genotypes showed various values of root dry weight. It was reported that the various genotypes of similar species of cultivated crops showed different plant architecture including root dry weight. Genetic information of a crop plants have dominant roles to a variety of crops on root dry weight. Therefore, all together these data suggest that BD-6985 possessed highest root dry weight than other genotypes of sesame of this study. The root dry weight of different genotypes at harvest showed significant variation to waterlogging stress at different age of the plants (Table 16, Appendix 11). The lowest root dry weight (0.54g) was found under waterlogging stress which imposed to different sesame plant at the age of 50 d whereas the highest root dry weight (0.74g) was found from control. The root dry weight showed lower reduction at the age of 40 d than the age of 30 d of waterlogging stress. These results indicate that the rate of reduction of root fresh weight are variable to waterlogging at different age of

the plant. The interaction effects of sesame genotypes and waterlogging at different age of the plant showed significant variations on root dry weight of sesame (Table 17, Appendix 11). In this study, ten different genotypes were used which were taken from experiment 1 and waterlogging was imposed at different age of the plant. The root dry weight was recorded in all treatment combination to waterlogging stress in all genotypes compared to control treatment combination. The highest root dry weight (0.93 g) was found from the treatment combination of BD-6985 and control. The root dry weight was declined to waterlogging at different age of the plant in all aspect. The rate of the reduction of root dry weight were almost similar trend to waterlogging at different age of the plant. In all genotypes root dry weight reduction were much higher under waterlogging stress; vegetative stage (30 d) andreproductive stage (50 d age of the plant) than the early reproductive stage (40 d age of the plant). These results also highlighted that sesame plants have more capacity to enhance root dry weight at early reproductive stage (40 d age of the plant) than vegetative and reproductive period under waterlogging stress. The lowest root dry weight (0.46 g) was recorded from the treatment combination of BD-6991 and waterlogging at 50 d age of the plant; followed by genotypes JP-14003 (0.47 g) and waterlogging at 50 d age of the plant treatment combination. Therefore, these results root dry weight decrease underwaterlogging condition in different sesame genotypes.

4.2.9. 1st fruit set

Effect of waterlogged treatments on 1st fruit set date of different sesame genotypes under different sowing time have been presented in (Table 18, Appendix 14). Different sowing dates showed statistically significant differences on 1st fruit set date. Control plant showed highest date (58.76) followed by 40 d recorded date (58.50), however, which was statistically significant at with 30 d and 50 d respectively. The lowest date (56.00) was observed from30 d.

Table 18: Effect of waterlogged treatments on 1st fruit set and plant maturity of different sesame genotypes under different sowing time

Age of plant	1st fruit set	Plant maturity
Control	58.76 a	78.66 a
30D	57.16 b	76.03 b
40D	58.50 a	77.90 a
50D	57.00 b	75.50 b
CV (%)	2.22	2.14
$LSD_{(0.05\%)}$	0.66	0.84

Values followed by same letters are not significantly different from each other by LSD at 5% level for each other.

Effect of waterlogged treatments on 1st fruit set date of different sesame genotypes under different variety have been presented in (Table 19, Appendix 14). Different varieties showed statistically significant differences on 1st fruit set date. JP-00411 recorded the highest day (58.75) followed by JP-03013 recorded day (58.66), however, which was statistically significant at with other varieties. The lowest day (56.91) was observed from BD-6996.

Table 19: Effect of waterlogged treatments on 1st fruit set and plant maturity of different sesame genotypes under different variety.

Varieties	1sr fruit set	Plant maturity
BD 7008	57.41 bcd	76.66 bcd
BD-6985	58.33 ab	78.41 a
BD-6998	58.00 abc	77.41 abc
JP-00411	58.75 a	77.58 ab
JP-03013	58.66 a	76.08 cd
JP-14003	57.50 bcd	76.83 bcd
JP 01811	56.91 cd	76.91 ab
BD-6996	57.08 d	77.58 bcd
BD-6991	57.91 abcd	75.75 d
GP 83-3	58.00 abc	77.00 bcd
CV (%)	2.22	2.14
$LSD_{(0.05\%)}$	1.04	1.33

Values followed by same letters are not significantly different from each other by LSD at 5% level for each other.

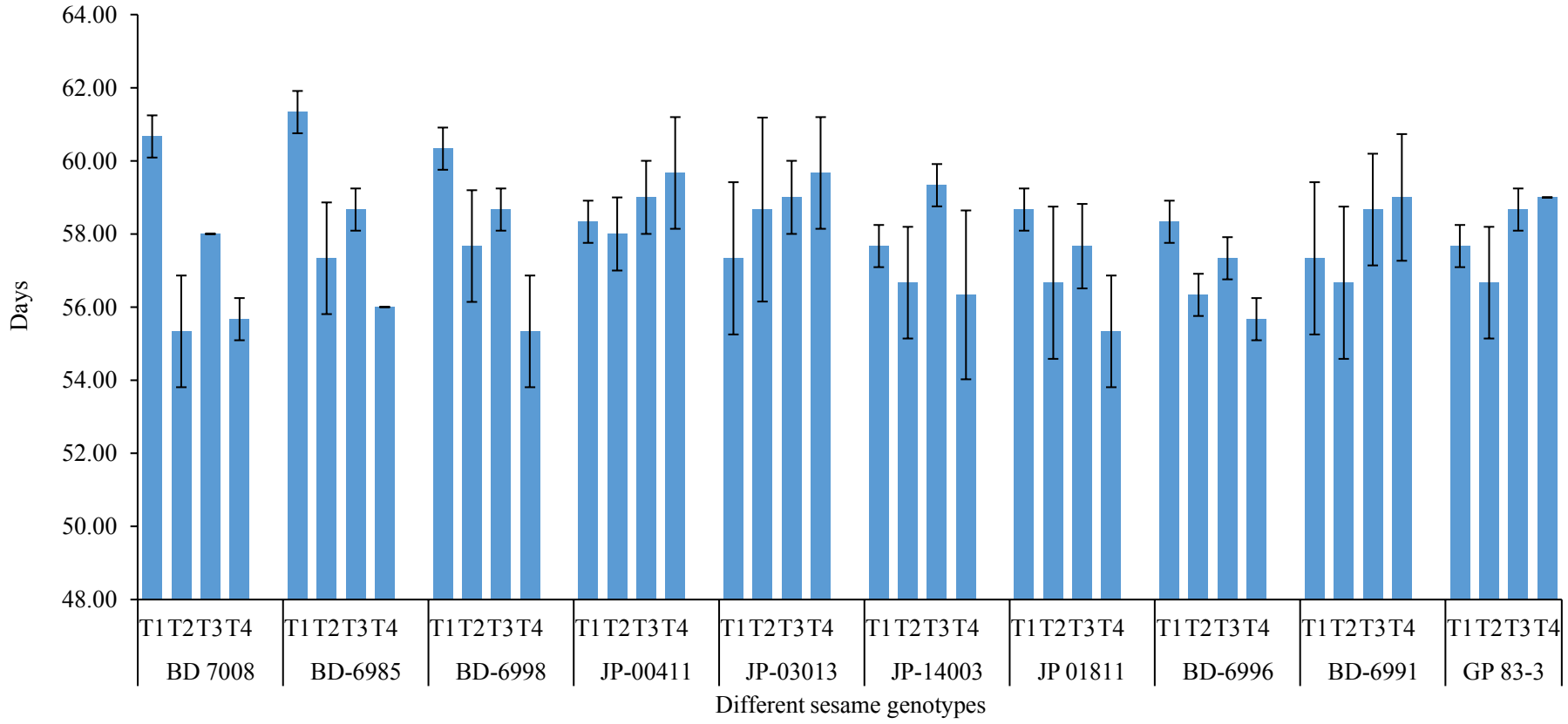

Figure.11. 1st fruit set of different sesame genotypes under 48 hrs waterlogging condition with different D, here T_1= Control, T_2= 30 D, T_3= 40 D, T_4= 50 D. $LSD_{0.05\%}$ =2.09. (Error bar shown value of standard deviation)

1st fruit set days were significantly differed among all the genotypes with variety (Appendix 14). Among *Sesamum indicum* genotypes, highest fruit set initiation days was recorded by BD-6985 (61.33 days) at control condition followed by BD-7008 (60.67 days) at control condition (Fig. 29; Table 20, Appendix 14). Control plant recorded mixed 1st fruit set day than treatments due to different waterlogged condition enhanced early fruiting in order to survive for next generation and minimum 1st fruit set day was recorded for JP 01811 (55.33 days) at 50D followed by BD-6998 (55.33 days) at 50D (Table 20, Appendix 14). Control plant recorded higher 1st fruit set day than treatments due to different waterlogged condition enhanced early flowering in order to survive for next generation.

Table 20. Interaction effect of waterlogged treatments on 1st fruit set and plant maturity of different sesame genotypes.

Genotypes x Age of plant (Interaction)		1sr fruit set	Plant maturity
BD 7008	Control	60.66 ab	80.66 ab
	30D	55.33 j	75.00 h-j
	40D	58.00 d-h	76.66 c-i
	50D	55.66 ij	74.33 ij
BD-6985	Control	61.33 a	81.00 a
	30D	57.33 e-j	77.66 c-h
	40D	58.66 b-f	78.33 a-f
	50D	56.00 h-j	76.66 c-i
BD-6998	Control	60.33 a-c	79.33 a-c
	30D	57.66 d-i	76.33 d-i
	40D	58.66 b-f	78.66 a-e
	50D	55.33 j	75.33 g-j
JP-00411	Control	58.33 c-g	78.33 a-f
	30D	58.00 d-h	78.00 b-g
	40D	59.00 b-e	79.00 a-d
	50D	59.66 a-d	75.00 h-j
JP-03013	Control	57.33 e-j	77.33 c-h
	30D	58.66 b-f	73.33 j
	40D	59.00 b-e	78.33 a-f
	50D	59.66 a-d	75.33 g-j
JP-14003	Control	57.66 d-i	77.66 c-h
	30D	56.66 f-j	76.33 d-i
	40D	59.33 a-e	77.66 c-h
	50D	56.33 g-j	75.66 f-j
JP 01811	Control	58.66 b-f	79.00 a-d
	30D	56.66 f-j	77.33 c-h
	40D	57.66 d-i	78.66 a-e
	50D	55.33 j	75.33 g-j
BD-6996	Control	58.33 c-g	78.33 a-f
	30D	56.33 g-j	76.66 c-i
	40D	57.33 e-j	77.66 c-h
	50D	55.66 ij	75.00 h-j
BD-6991	Control	57.33 e-j	77.33 c-h
	30D	56.66 f-j	73.33 j
	40D	58.66 b-f	76.33 d-i
	50D	59.00 b-e	76.00 e-j
GP 83-3	Control	57.66 d-i	77.66 c-h
	30D	56.66 f-j	76.33 d-i
	40D	58.66 b-f	77.66 c-h
	50D	59.00 b-e	76.33 d-i
CV (%)		2.22	2.14
LSD $_{(0.05\%)}$		2.09	2.67

Values followed by same letters are not significantly different from each other by LSD at 5% level for each other.

4.2.10 Maturity days

Effect of waterlogged treatments on maturity date of different sesame genotypes under different sowing time have been presented in (Table 18, Appendix 15). Different sowing dates showed statistically significant differences on maturity date. Control plant showed highest date (78.66) followed by waterlogged at 40D recorded date (77.9), however, which was statistically significant at with 30D and 50D respectively. The lowest date (75.5) was observed from 50D. Effect of waterlogged treatments on maturity date of different sesame genotypes under different variety have been presented in (Table 19, Appendix 15). Different varieties showed statistically significant differences on maturity date. BD-6985 recorded the highest day (78.41), however, which was statistically significant at with other varieties. The lowestday (75.75) was observed from BD-6991.

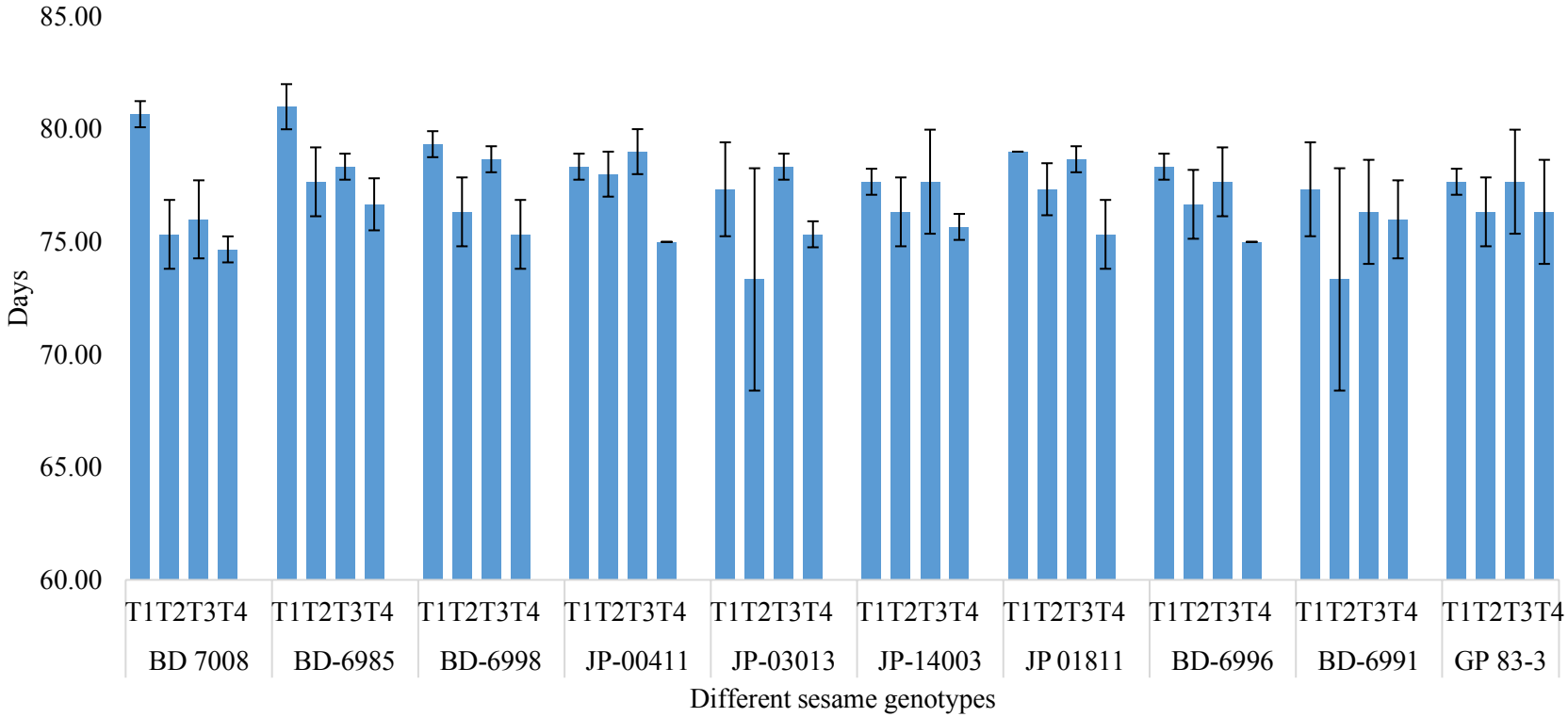

Fig.12. Maturity days of different sesame genotypes under 48 hrs waterlogging condition with different D, here T_1= Control, T_2= 30 D, T_3= 40 D, T_4= 50 D. $LSD_{0.05\%}$ =2.67 (Error bar shown value of standard deviation)

Maturity days were significantly differed among all the genotypes with variety (Appendix 15). Among *Sesamum indicum* genotypes, highest maturity day was recorded by BD-6985 (81 days) at control condition followed by BD-7008 (80.67 days) atcontrol condition (Table 20). Control plant recorded mixed maturity day than treatments due to different waterlogged condition enhanced early maturity in order to survive for next generation. However, minimum maturity day was recorded for BD-6991 (73.33 days) 30D followed by JP-03013 (73.33 days) 30D (Table 20, Appendix 15).

4.2.11 Pods plant^{-1}

Effect of waterlogged treatments on number of pods per plant of different sesame genotypes under different sowing time have been presented in (Table 21, Appendix 16). Different sowing dates showed statistically significant differences on number of pods per plant. Control plant showed highest number (35.20) followed by 30D recorded number (34.73), however, which was statistically not significant at with 40D and 50D respectively. The lowest number (33.50) was observed from 50D. Genotypes differed significantly for number of capsules plant^{-1}. Among *Sesamum indicum* genotypes highest number of capsules plant^{-1} wasrecorded by Ayali (97.6) and it was significantly different from all other genotypes. Itwas lowest for SV 2 (46.6) (V. Athul. 2016). According to V. Athul. (2016) the wild species *Sesamum Malabaricum* recorded a lower value than that of SV 2 (41.3). Five genotypes had above general mean (65.3) and control plants had higher number of capsules than treatments.

Table 21: Effect of waterlogged treatments on number of pods per plant, number of seeds per plant, 1000 seed weight and yield of different sesame genotypes under different sowing time.

Age of plant	No. of pod/plant	No. of seed/plant	1000 seed weight(g)	Yield (t/ha)
Control	35.20 a	69.60 a	9.93 a	0.86 a
30D	34.40 ab	67.63 b	7.20 c	0.68 b
40D	34.73 ab	69.13 a	8.40 b	0.70 b
50D	33.50 b	67.23 b	7.00 c	0.63 c
CV (%)	8.36	1.83	9.43	7.98
$LSD_{(0.05\%)}$	1.48	0.64	0.39	0.02

Values followed by same letters are not significantly different from each other by LSD at 5% level for each other.

Effect of waterlogged treatments on number of pods per plant of different sesame genotypes under different variety have been presented in (Table 22, Appendix 16). Different varieties showed statistically significant differences on number of pods per plant. BD-6998 recordedthe highest number (36.00) followed by BD-7008 recorded the number (36.00), however, which was statistically not significant at with other varieties. The lowest number (32.41) was observed from GP-83-3.

Table 22: Effect of waterlogged treatments on number of pods per plant, number of seeds per plant, 1000 seed weight and yield of different sesame genotypes under different variety.

Genotypes	No. of pod/plant	No. of seed/plant	1000 seed weight(g)	Yield (t/ha)
BD 7008	36.00 a	66.75 d	8.66 ab	0.85 b
BD-6985	35.66 a	68.83 ab	9.08 a	0.95 a
BD-6998	36.00 a	69.08 ab	8.33 bc	0.76 c
JP-00411	34.50 abc	67.75 cd	8.00 cd	0.64 de
JP-03013	33.16 bc	69.33 a	8.66 ab	0.63 e
JP-14003	32.41 c	68.50 abc	8.33 bc	0.64 de
JP 01811	35.75 ab	68.16 cd	7.41 d	0.68 c
BD-6996	35.50 a	67.75 bc	7.66 d	0.74 d
BD-6991	33.16 bc	69.33 a	7.50 d	0.63 e
GP 83-3	32.41 c	68.50 abc	7.66 d	0.64 de
CV (%)	8.36	1.83	9.43	7.98
$LSD_{(0.05\%)}$	2.34	1.02	0.62	

Values followed by same letters are not significantly different from each other by LSD at 5% level for each other.

Number of pods per plant were significantly differed among all the genotypes with variety (Appendix 16). Among *Sesamum indicum* genotypes, the highest number of pods was recorded by BD-7008 (39.33) at control followed by BD-6998 (38) at control and lowest number of pods was recorded and minimum number of pods was recorded for BD-6991 (31.67) followed by GP 83-3 (31.67) (Table 23). Control plant recorded higher number of pods per plant than treatments due to different waterlogged. Number of capsules $plant^{-1}$ were high in control for all the genotypes. Waterlogged condition reduced the number of capsules $plant^{-1}$. Similar results were reported by Ghoi *et al.* (1996) and Gutierrez *et al.* (1996).

Table 23: Effect of waterlogged treatments on pod per plant, number of seeds per plant, 1000 seed weight and yield of different sesame genotypes.

Genotypes x Age of plant (Interaction)		No. of pod/plant	No. of seed/plant	1000 seed weight(g)	Yield
BD 7008	Control	39.33 a	70.66 bc	11.00 ab	1.13 a
	30D	34.66 a-f	65.66 lm	7.33 j-m	0.81 ef
	40D	35.33 a-f	66.00 j-m	9.3 d-g	0.86 c-e
	50D	34.66 a-f	65.00 m	7.00 k-m	0.69 g-i
BD-6985	Control	37.00 a-d	72.66 ab	1.66 a	1.11 a
	30D	35.33 a-f	67.00 h-m	7.66 i-l	0.86 c-e
	40D	36.66 a-e	69.66 c-f	9.66 c-f	1.00 b
	50D	33.66 b-f	66.00 j-m	7.33 j-m	0.85 c-e
BD-6998	Control	38.00 ab	73.33 a	10.66 abc	0.92 b-d
	30D	35.00 a-f	68.00 e-j	7.00 k-m	0.64 h-l
	40D	37.66 ab	69.66 c-f	8.66 f-i	0.83 de
	50D	33.33 b-f	65.33 lm	7.00 k-m	0.65 h-k
JP-00411	Control	35.00 a-f	68.33 d-i	10.00 b-e	0.70 gh
	30D	34.66 a-f	68.00 e-j	6.66 lm	0.59 i-l
	40D	32.66 c-f	69.00 d-h	8.33 g-j	0.59 j-l
	50D	35.66 a-f	65.66 k-m	7.00 k-m	0.67 h-k
JP-03013	Control	31.66 f	67.33 g-l	10.33 b-d	0.72 f-h
	30D	34.00 b-f	70.00 c-e	8.00 h-k	0.66 h-k
	40D	34.66 a-f	70.33 cd	9.00 e-h	0.59 j-l
	50D	32.33 d-f	69.66 c-f	7.33 j-m	0.55 l
JP-14003	Control	32.66 c-f	67.66 f-k	9.66 c-f	0.78 e-g
	30D	33.33 b-f	66.66 i-m	7.66 i-l	0.69 g-i
	40D	31.66 f	69.33 c-g	9.00 e-h	0.56 l
	50D	32.00 ef	70.33 cd	7.00 k-m	0.55 l
JP 01811	Control	37.33 a-c	70.33 cd	9.33 d-g	0.94 bc
	30D	35.00 a-f	66.66 i-m	6.66 lm	0.64 h-l
	40D	36.33 a-f	68.66 c-i	7.33 j-m	0.71 gh
	50D	33.33 b-f	65.33 lm	7.33 j-m	0.67 hij
BD-6996	Control	36.66 a-e	70.66 bc	8.66 f-i	0.86 c-e
	30D	34.66 a-f	68.00 e-j	6.66 lm	0.58 j-l
	40D	36.00 a-f	69.00 c-h	7.33 j-m	0.72 f-h
	50D	35.66 a-f	65.00 m	7.0 k-m	0.57 kl
BD-6991	Control	31.66 f	67.33 g-l	9.00 e-h	0.72 f-h
	30D	34.00 b-f	70.00 c-e	7.00 k-m	0.66 h-k
	40D	34.66 a-f	70.33 cd	7.66 i-l	0.59 j-l
	50D	32.33 d-f	69.66 c-f	6.33 m	0.55 l
GP 83-3	Control	32.66 c-f	67.66 f-k	9.00 e-h	0.78 e-g
	30D	33.33 b-f	66.66 i-m	7.33 j-m	0.69 g-i
	40D	31.66 f	69.33 c-g	7.66 i-l	0.56 l
	50D	32.00 ef	70.33 cd	6.66 lm	0.55 l
CV (%)		8.36	1.83	9.43	7.98
$LSD_{(0.05\%)}$		4.68	2.04	1.24	0.09

Values followed by same letters are not significantly different from each other by LSD at 5% level for each other.

4.2.12 Seed pod^{-1}

Effect of waterlogged treatments on number of seed per pod of different sesame genotypes under different sowing time have been presented in (Table 21, Appendix 17). Different sowing dates showed statistically significant differences on number of seed per pod. Control plant showed highest number (69.60) followed by 40D recorded the highest number (69.13), however, which was statistically significant at with 30D and 50D respectively. The lowest number (67.23) was observed from 50D. Genotypes differed significantly for number of seeds capsule^{-1}. Among the *Sesamum indicum* genotypes highest number of seeds per capsule was recorded by Ayali (42) and it is significantly different from all other genotypes. SV 2 recorded lowest number of seeds capsule^{-1} (30.0) (V. Athul. 2016).

Effect of waterlogged treatments on number of seed per pod of different sesame genotypes under different variety have been presented in (Table 22, Appendix 17). Different varieties showed statistically significant differences on number of seed per pod. JP-03013 recorded the highest number (69.33) followed by BD-6991 recorded the highest number (69.33), however, which was statistically significant at with other varieties. The lowest number (66.75) was observed from BD-7008. Number of seed per plant were significantly differed among all the genotypes with variety (Appendices 3, 4). Among *Sesamum indicum* genotypes, the highest number of seed was recorded by BD-6998 (73.33) at control followed by BD-6985 (72.67) at control (Table 23). Control plant recorded higher number of seed per plant than treatments due to different waterlogged condition. However, minimum number of seed was recorded by BD-6996 (65.00) followed by BD-7008 (65.) (Table 23, Appendix 17).

4.2.13 1000 seed weight

Effect of waterlogged treatments on thousand seed weight of different sesame genotypes under different sowing time have been presented in (Table 21, Appendix 18). Different sowing dates showed statistically significant differences on thousand seed weight. Control plant showed highest weight (9.93 g) followed by 40 d recorded the highest weight (8.4 g), however, which was statistically significant at with 30 d and 50 d respectively.

The lowest weight (7.00 g) was observed from 50 d. Significant difference was observed among all the genotypes for thousand seed weight. Wild species *Sesamum Malabaricum* recorded lowest thousand seed weight (2.41 g). Among the *Sesamum indicum* genotypes highest 1000 seed weight was recorded by SV 2 (3.01 g) (V. Athul. 2016). 1000 seed weight lowest for Ayali (2.52 g). Five genotypes had above general mean (2.70 g) and thousand seed weight was more for control plants (V. Athul. 2016).

Effect of waterlogged treatments on thousand seed weight of different sesame genotypes under different variety have been presented in (Table 22, Appendix 18). Different varieties showed statistically significant differences on thousand seed weight. BD-6985 recorded the highest weight (9.08 g) followed by BD-7008 recorded the weight (8.66 g), however, which was statistically significant at with other varieties. The lowest weight (7.41 g) was observed from BD-6996. Thousand seed weight were significantly differed among all the genotypes with variety (Appendix 18). Among *Sesamum indicum* genotypes, the highest seed weight was recorded by BD-6985 (11.67 g) at control condition followed by BD-7008 (11.00 g) at control condition and lowest weight was recorded for BD-6991 (6.33 g) at 50 d followed by GP-83-3 (6.66 g) (Table 23, Appendix 18). Control plant recorded higher thousand seed weight than treatments due to different waterlogged condition.

4.2.14 Yield

The yield of sesame showed significant reduction to waterlogging at different days after sowing (Table 21, Appendix 19) The height of sesame plant exhibited maximum decrease to waterlogging condition 50 d whereas the lowest decline was found at 40 d compared waterlogging at 50 d. Different sowing dates showed statistically significant differences on yield. Control plant showed highest yield (0.86 ton) followed by 40 d recorded the highest yield (0.703 ton), however, which was statistically significant at with 30 d and 50 d respectively. The lowest yield (0.633 ton) was observed from 50 d. Genotypes differed significantly for yield per plant. Among cultivated species highest yield plant^{-1} was for Ayali (7.46 g) which was similar with Thilak. Lowest yield plant^{-1} was for SV 2 (3.65 g). Wild species *Sesamum malabaricum* recorded lowest yield (2.92 g). Five genotypes

recorded yield plant $^{-1}$ above general mean (5.36 g) and control plants recorded more yield than treated plants (V. Athul. 2016). Significant difference was observed among all the genotypes for yield plot^{-1}. Among cultivated species highest yield plot^{-1} was for Ayali (201.4g) and lowest for SV 2 (63.03 g). Wild species *Sesamum malabaricum* recorded yield plot^{-1} of 85.38 g. five genotypes recorded higher yield plot^{-1} than general mean (123.06 g) and control plots had more yield per plot than treatments (V. Athul. 2016).

Effect of waterlogged treatments on yield of different sesame genotypes under different variety have been presented in (Table 22, Appendix 19). Different varieties showed statistically significant differences on yield. BD-6985 recorded the highest yield (0.95 ton), however, which was statistically significant at with other varieties. The lowest yield (0.6317 ton) wasobserved from BD-6991. Yield was significantly differed among all the genotypes with variety (Appendix 19). Among *Sesamum indicum* genotypes, the highest yield was recorded by BD-7008 (1.13 t/ha) at control condition followed by BD-6985 (1.11 t/ha) at control condition and lowest yield was recorded for BD-6991 (0.55 t/ha) at 50D followed by JP-03013 (0.55 t/ha) (Table 23). Control plant recorded higher thousand seed weight than treatments due to different waterlogged condition. Seed yield is the most desirable character for breeders to develop a variety. Waterlogging tolerance drastically reduces theyield of plants. These may be due to reduced photosynthetic rate. Water logged condition creates loss of chlorophyll content and it eventually leads to reduction in photosynthetic rate, hence yield. There was a reduction in yield in all the genotypes by waterlogging which may be due to the reduction in the yield attributing characters. The results are in accordancewith the findings of Sparrow and Uren (1987) in cowpea, Marashi and Chinchanikar (2014)in wheat and Sarkar *et al*. (2016) in sesame.

Experiment III. Physiological, biochemical and molecular mechanism of water logging tolerance in sesame.

The physiological and biochemical responses of sesame to waterlogging stress was investigated. The dynamics and mechanisms of action of anaerobic proteins and antioxidant enzymes in waterlogged sesame were explored. The mechanisms of ROS and methylglyoxal detoxification system in waterlogged sesame were examined. The mechanisms of anatomic adaptations in waterlogged sesame were explored.

4.3.1. Anatomical study:

Two tolerant and two susceptible genotypes were grown in pot under control and waterlogging at vegetative stage for 3 days. Pots were submerged in concrete house where water were kept in such a way that at least 3-5 cm of the stem remain under water for three days. At the end of stress, pots were bringing out from water and examined the all the physiological, biochemical and anatomical analysis.

4.3.2. Determination of Chlorophyll Content

Waterlogging reduced the chlorophyll content in all the genotypes. For BD-7008 chlorophyll content (0.41) after waterlogging was less than control (0.81), there was significant difference between waterlogging treatment and control for chlorophyll content. Total chlorophyll, chlorophyll a and chlorophyll b content were highest in BD-6985 (0.45) and lowest in BD-6996 (0.33) (Fig. 23)

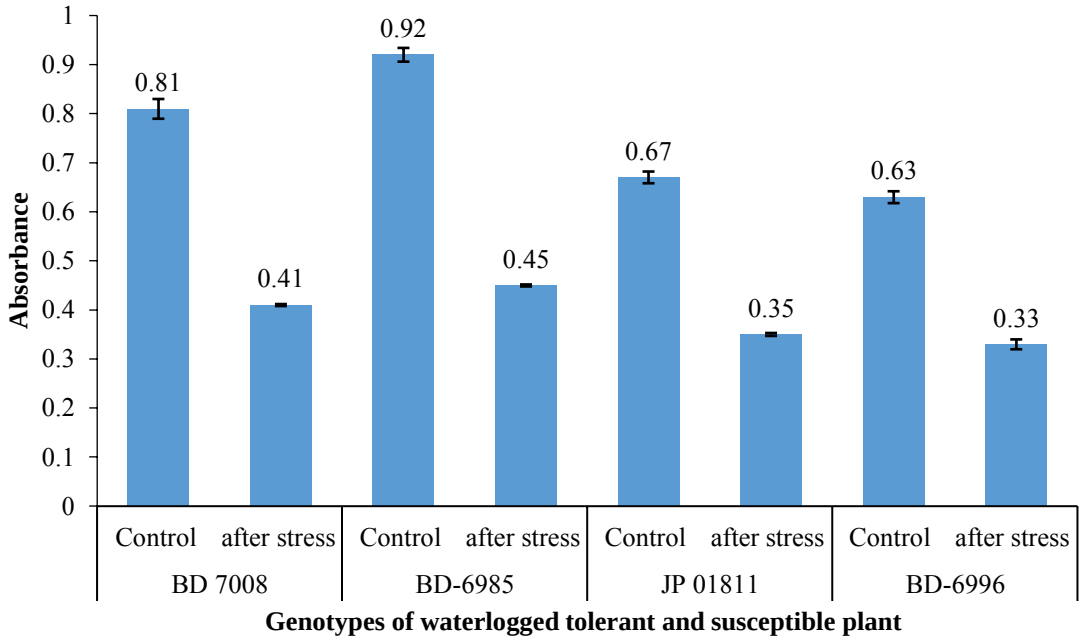

Figure. 13. Chlorophyll content of different sesame tolerant and susceptible genotypes under waterlogging at growing stage during water logging condition.

According to V. Athul. (2016) waterlogging reduced the chlorophyll content in all the genotypes. Since t-statistic for chlorophyll content (7.21) after waterlogging was more than table t value (2.26), there was significant difference between waterlogging treatment and control for chlorophyll content. Total chlorophyll, chlorophyll a and chlorophyll b content were highest in Ayali (0.56 mg g^{-1}) and lowest in SV 2 (0.20 mg g^{-1}). Similar observations were made by Wang *et al.* (1999) in sesame. Maximum chlorophyll retention was exhibited by tolerant variety Ayali.

4.3.3. Determination of Proline content:

Proline content was found to be increased by waterlogging. Proline content after waterlogging was compared with control and presented in (Fig 24). There was significant difference between waterlogging treatment and control for proline. It was highest for the variety BD-6985 (1.025 µmol g^{-1}) after stress and lowest for JP 01811 (0.524 µmol g^{-1}). Waterlogging increased the concentration of proline by 50 % over control in BD-6985 (Table 24). According V. Athul. (2016) percentage of increase in proline content by

waterlogging was highest for Thilarani and lowest for TKG 308 over control. Waterlogging increased the concentration of proline by 49.79 % over control in *Sesamum malabaricum. Sesamum malabaricum* recorded highest proline content (2.41 mg g^{-1}).

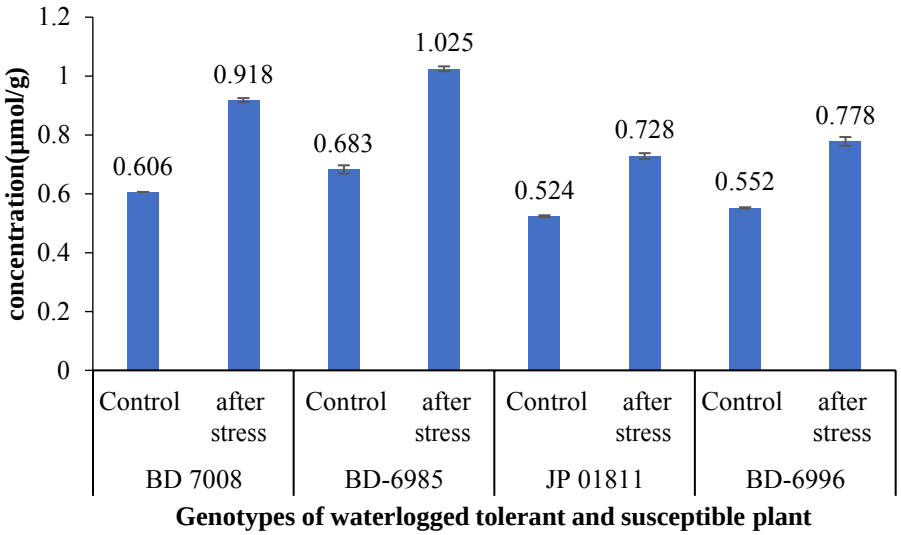

Figure. 14 Proline content of different sesame tolerant and susceptible genotypes under waterlogging at growing stage during water logging condition.

Waterlogging induces the production of the osmo-regulant such as proline in the plant system. In waterlogging increased the concentration of proline and it was highest for the variety BD-6985 and lowest for JP 01811 in *Sesamum indicum*. *Sesamum malabaricum* recorded highest proline content. The report of Xing and Cai (1998) is in agreement with this result

4.3.4. Determination of SOD content:

Stress condition causes the formation of free radicals in the plant system causing senescence of plants. Which will lead to the production of antioxidants to protect the plant system. SOD is one of the antioxidants produced during stress situations. Increase in SOD activity under flooding stress is an indication of an increased production of reactive oxygen species. In the present investigation also, it was found that SOD content increased in all the genotype under waterlogged condition. Studies of Yan *et al.* (1996) and Xu *et al*. (2012) in sesame reported similar results.

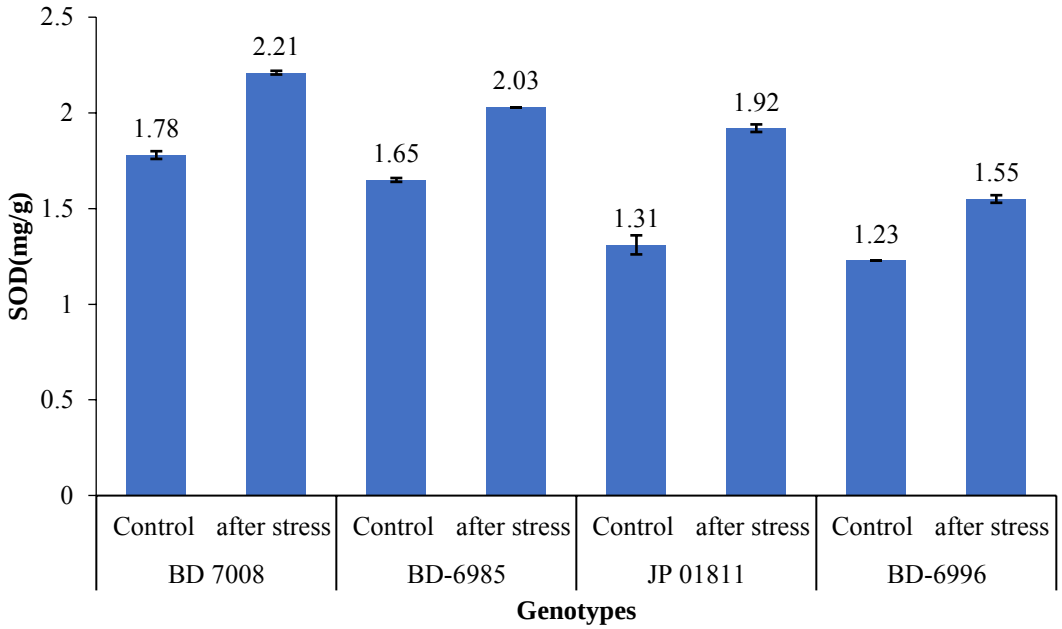

Figure. 15 SOD content of different sesame tolerant and susceptible genotypes under waterlogging at growing stage during water logging condition.

There was significant difference between waterlogging treatment and control for SOD. SOD was found to be increasing by waterlogging. Waterlogging enhanced the SOD content in all the genotypes. For BD-7008 SOD content (2.21 unit mg^{-1} protein) after waterlogging was less than control (1.78 unit mg^{-1} protein), there was significant difference between waterlogging treatment and control for SOD content. Total SOD content was highest in BD-7008 (2.21 unit mg^{-1} protein) and lowest in BD- 6996 (1.55 unit mg^{-1} protein) (Fig. 25). Waterlogging increased the concentration of SOD by 46 % over control in JP-01811 .

Excessive formation of reactive oxygen species (ROS) is an integral part of many stress situations, including hypoxia. Super oxide dismutase (SOD) is an antioxidant present under abiotic stress condition and its activity is increased in cells under waterlogging and is vital in the protection of plants against oxidative stress. Short anoxic stress increased the potential for superoxide production and it has a crucial role in the survival of the plant during flooding stress (Van Toai and Bolles, 1991). Yan *et al.* (1996) reported that prolonged flooding led to an increase in the activities of SOD in maize. Xu *et al*. (2012) reported that SOD activities in sesame leaves increased due to flooding and SOD activity in the flood tolerant sesame genotype WTG is increasing more than that of the susceptible genotype WSG.

4.3.5. Determination of POD content

There was significant difference between waterlogging treatment and control for POD. POD was found to be increasing by waterlogging. Waterlogging enhanced the POD content in all the genotypes. For BD-7008 POD content (0.389 unit mg^{-1} protein) after waterlogging was less than control (0.273 unit mg^{-1} protein), there was significant difference between waterlogging treatment and control for POD content. Total POD content was highest in BD-7008 (0.389 unit mg^{-1} protein) and lowest in BD-6996 (0.219 unit mg^{-1} protein) (Fig. 26). Waterlogging increased the concentration of POD by 42 % over control in BD-7008.

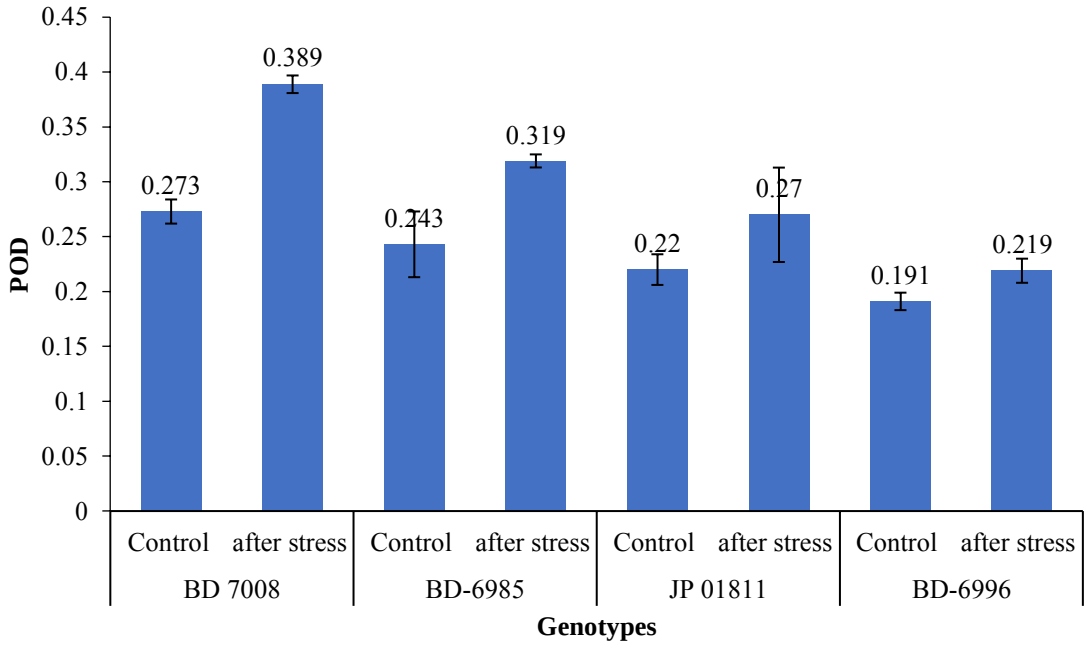

Figure. 16. POD content of different sesame tolerant and susceptible genotypes under waterlogging at growing stage during water logging condition.

4.3.6. Determination of CAT content:

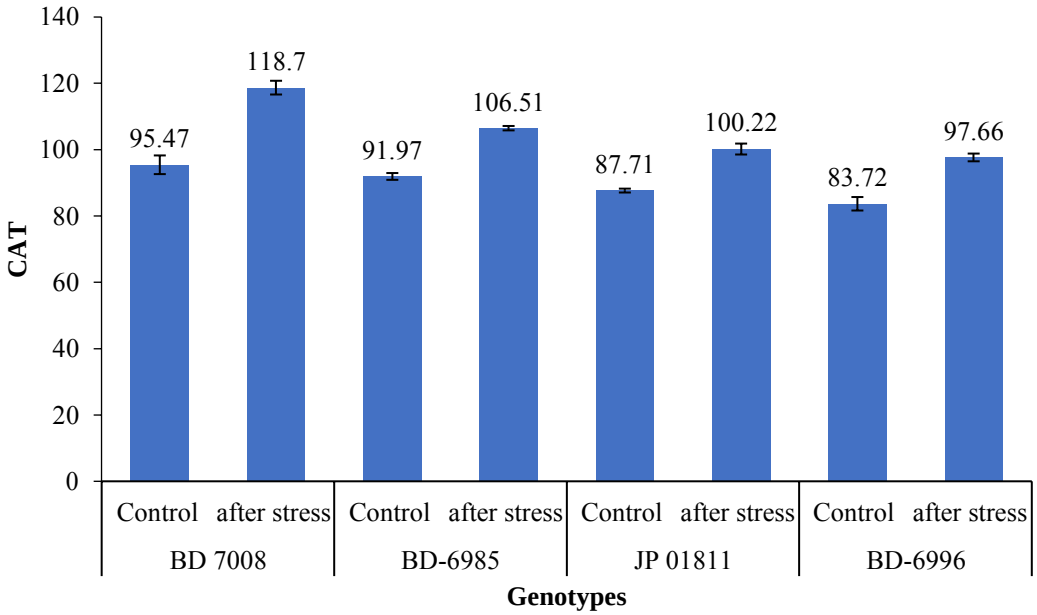

Figure. 17. CAT content of different sesame tolerant and susceptible genotypes under waterlogging at growing stage during water logging condition.

There was significant difference between waterlogging treatment and control for CAT. CAT was found to be increasing by waterlogging. Waterlogging enhanced the CAT content in all the genotypes. For BD-7008 POD content (118.7 unit mg^{-1} protein) after waterlogging was less than control (95.47 unit mg^{-1} protein), there was significant difference between waterlogging treatment and control for POD content. Total POD content was highest in BD-7008 (118.7 unit mg^{-1} protein) and lowest in BD-6996 (97.66 unit mg^{-1} protein) (Fig. 27). Waterlogging increased the concentration of CAT by 24 % over control in BD-7008.

Chapter V

SUMMARY AND CONCLUSIONS

Preliminary screening of one hundred nineteen genotypes for tolerance and susceptible to waterlogging was conducted during *Rabi* season 2016-2018. Waterlogging was imposed at four different duration i.e., 12 hours, 24 hours, 48 hours and 72 hours. All the plants after 72h waterlogged condition were died except control. Among them BD-6985, BD-6998, BD-7003, BD-7004, BD-7008, BD-7018, JP-00411, JP-03013 and JP-14003 were found better tolerance regarding survivability compare to others where genotypes BD-6959, BD- 6980, BD-6981, BD-6984, BD-6991, BD-6996, GP 83-3, GP 53-1, GP 5, JP-01811 and BARI Til 4 were found more susceptible compared to others.

All the sixteen genotypes were survived in 12 h, 24 h and 48 h of waterlogging conditions. Survival percentage varied from 40 percentage (BD-6991) to 100 percentage (BD-6998) under 48 h of waterlogging. The same genotypes recorded lowest (60 percentage) and highest survival (100 %) under 24 h of waterlogging also. But no genotypes survived at 72 h of waterlogging. Maximum survival was recorded by BD-6998. Among the cultivated genotypes, maximum survival was recorded by BD-6998 (100%) and minimum by BD-6991 (40%) at 48 h.

The WTC was expressed tolerance and susceptible capability of a plant under waterlogged condition. Therefore, BD-6998, BD-6985 and BD-7008 were more tolerant plant compared to others whereas BD-6996 and JP-01811 were susceptible genotypes.

Tolerant were highest plant height compared to susceptible plant. As well as all the phonological character showed the same trend. Moreover, in yield contributing characters also showed the same trend. Sesame tolerant highest plant height was recorded by BD-6985 (104.66 cm) at control followed by BD-6985 (102 cm) at 40 D. Control plant recorded higher plant height than treatments. The percentage of plant height reduction was average 25% due to water logged condition. Highest plant height was recorded by JP 01811 (78.66 cm) followed by GP-83-3 (77.33 cm) for the susceptible plant. Highest number of plants

leaves were recorded by BD-6985 (28) followed by BD-6985 (25.33) for tolerant plant whereas highest number of leaves was recorded by JP-83-3 (21.67) followed by BD-6998 (21.33) for susceptible plant.

Seed yield is the most desirable character for breeders to develop a variety. Waterlogging tolerance drastically reduces the yield of plants. These may be due to reduced photosynthetic rate. Water logged condition creates loss of chlorophyll content and it eventually leads to reduction in photosynthetic rate, hence yield. There was a reduction in yield in all the genotypes by waterlogging which may be due to the reduction in the yield attributing characters.

Among *Sesamum indicum* genotypes, the highest yield was recorded by BD-7008 (1.13 t/ha) followed by BD-6985 (1.11 t/ha) for tolerant plant whereas among *Sesamum indicum* genotypes, the highest yield was recorded by JP 01811 (0.95 t/ha) followed by BD-6996 (0.86 t/ha) for susceptible variety.

In the investigation root anatomy was studied for the four genotypes. The genotypes viz, the BD-7008, BD-6985, BD-6996 and JP 01811 had significant formation of aerenchyma compared to others. This implies that these genotypes had more waterlogging tolerance than others.

Waterlogging reduced the chlorophyll content in all the genotypes. For BD-7008 chlorophyll content (0.41) after waterlogging was less than control (0.81), there was significant difference between waterlogging treatment and control for chlorophyll content. Proline content was found to be increased by waterlogging. There was significant difference between waterlogging treatment and control for proline. It was highest for the variety BD-6985 (1.025 µmol g^{-1}) after stress and lowest for JP 01811 (0.524 µmol g^{-1}). Waterlogging increased the concentration of proline by 50 % over control in BD-6985.

There was significant difference between waterlogging treatment and control for SOD. SOD was found to be increasing by waterlogging. Waterlogging enhanced the SOD content

in all the genotypes. For BD-7008 SOD content (2.21) after waterlogging was less than control (1.78), there was significant difference between waterlogging treatment and control for SOD content. There was significant difference between waterlogging treatment and control for POD. POD was found to be increasing by waterlogging. Waterlogging enhanced the POD content in all the genotypes. For BD-7008 POD content (0.389) after waterlogging was less than control (0.273). CAT was found to be increasing by waterlogging. Waterlogging enhanced the CAT content in all the genotypes. For BD-7008 POD content (118.7) after waterlogging was less than control (95.47), there was significant difference between waterlogging treatment and control for POD content.

Considering the above result, it may be summarized that morphological and yield contributing characters of sesame are negatively correlated with waterlogged condition. The mortality of sesame increased with increasing with waterlogged condition. The physiological and chemical properties of sesame also changed with waterlogged condition. Therefore, waterlogged hamper the germination, growth both morphological and physiological growth goes down slow. BD-7008 and BD-6985 were found more tolerant plant compared to JP-01811 and BD-6996 sesame plant.

Considering the situation of the present experiment, further studies in the following areas may be suggested:

1. Such study is needed in different agro-ecological zones (AEZ) of Bangladesh for fitness of the variety.
2. Molecular analysis is needed to identifying the behind mechanism of water-logged situation for better understanding waterlogged mechanism.

Chapter VI

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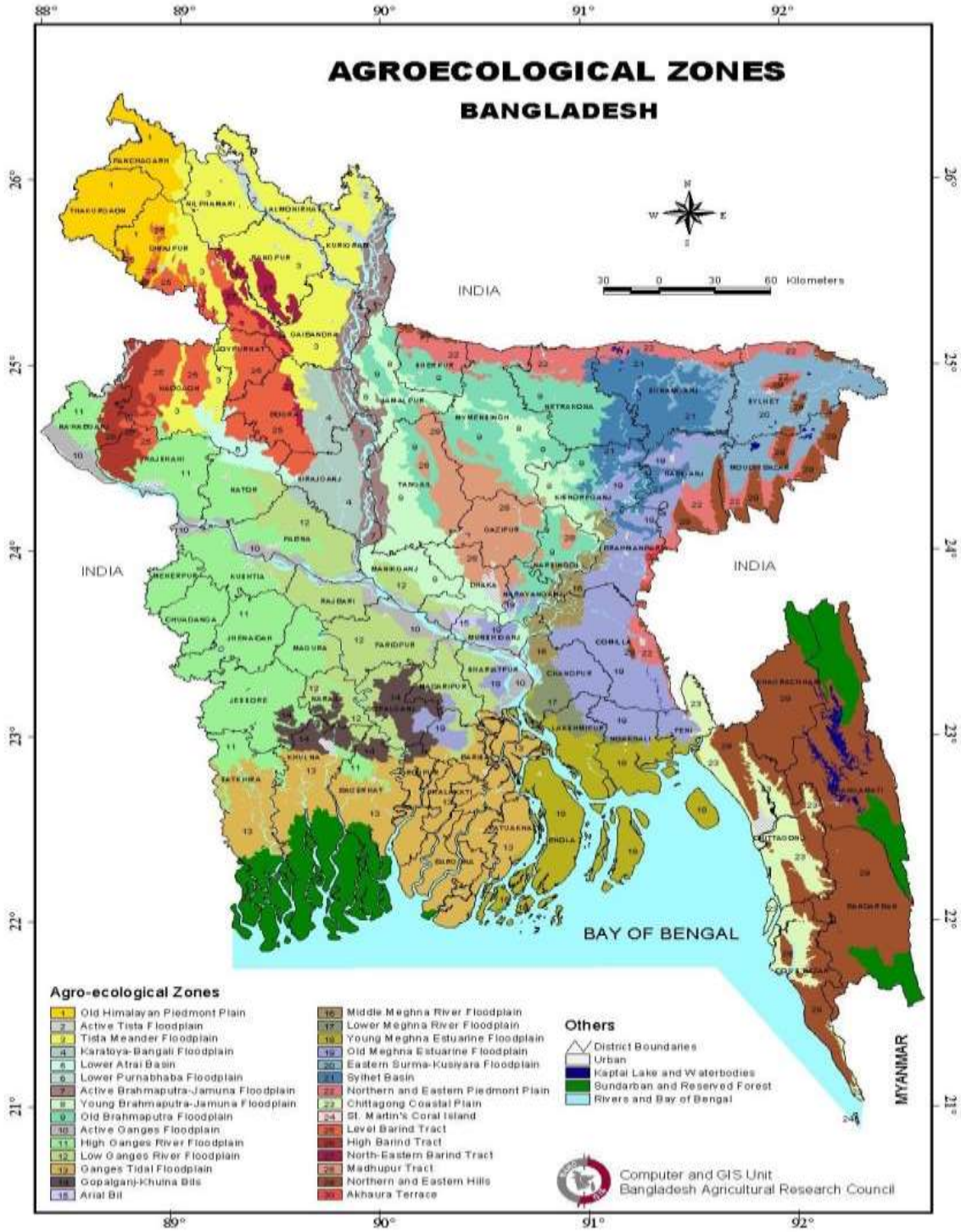
Chapter VII

APPENDIX

Appendix 1. The Map of the Experimental Site



Appendix 2. Physio-chemical characterization of the potted soil

Soil Characteristics	Analytical Value	Soil Characteristics	Analytical Value
Physical properties	Chemical properties		
Particle size distribution	Soil pH	5.59	
Sand	17.60%	Total N (%)	0.14
Silt	47.30%	Organic C (%)	0.68
Clay	35.1%	C: N ratio	5.0
Textual class	Silty clay loam	Available P (ppm)	6.68
Bulk density	1.40g/cm^3	Exchangeable K (meq/100g)	0.13
Particle density	2.61 g/cm^3	Available Sulphur (ppm)	13
Porosity (%)	47.4	Zn (ppm)	1.00

Appendix 3. Analytical protocols used for analysis of physio-chemical properties of soil

Parameteranalyzed	Methods	References
Soil texture class	Hydrometer method	Bouyoucos , 1962
Bulk density	Core sampler method	Blake, 1965a
Particle density	Pycnometer method	Blake, 1965b
Porosity	P = (1-bulk density/particle density) x100	Sharu *et al*., 2013
pH	Glass electrode pH method	Jackson, 1973
OC	Wet oxidation method	Walkley and Black, 1934a
Total N	Micro-Kjeldahl method	Bremner *et al*., 1982
Available P	Olsen's method	Jackson, 1973
Sulphur	Turbidimetric method	Hunter, 1984

Appendix 4. Factorial ANOVA table for plant Height

Factorial ANOVA Table for plant Height					
Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	9.4	4.72		
Varieties	9	14477.5	1608.61	508.91	0.0000
Sowing	3	2639.8	879.93	278.38	0.0000
Varieties*Sowing	27	477.5	17.69	5.60	0.0000
Error	78	246.6	3.16		
Total	119	17850.8			
Grand Mean 80.900					
CV 2.20					

Appendix 5. Factorial ANOVA table for number of leaves per plant

Factorial ANOVA Table for number of leaves per plant					
Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	7.82	3.908		
Varieties	9	338.33	37.593	37.83	0.0000
Sowing	3	662.83	220.944	222.32	0.0000
Varieties*Sowing	27	28.67	1.062	1.07	0.3972
Error	78	77.52	0.994		
Total	119	1115.17			
Grand Mean 20.083					
CV 4.96					

Appendix 6. Factorial ANOVA table for number of branches per plant

Factorial ANOVA Table for Number of branches per plant					
Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	3.817	1.9083		
Varieties	9	48.533	5.3926	9.67	0.0000
Sowing	3	247.667	82.5556	147.97	0.0000
Varieties*Sowing	27	10.333	0.3827	0.69	0.8640
Error	78	43.517	0.5579		
Total	119	353.867			
Grand Mean 7.8667					
CV 9.49					

Appendix 7. Factorial ANOVA table for shoot fresh weight

Factorial ANOVA Table for shoot fresh weight					
Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	2.875	1.438		
Varieties	9	132.217	14.691	17.70	0.0000
Sowing	3	583.517	194.506	234.37	0.0000
Varieties*Sowing	27	27.329	1.012	1.22	0.2462
Error	78	64.732	0.830		
Total	119	810.670			
Grand Mean	18.401				
CV	4.95				

Appendix 8. Factorial ANOVA table for shoot dry weight

Factorial ANOVA Table for shoot dry weight					
Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	0.1579	0.07896		
Varieties	9	2.1829	0.24255	4.74	0.0000
Sowing	3	5.3791	1.79302	35.03	0.0000
Varieties*Sowing	27	2.4771	0.09174	1.79	0.0245
Error	78	3.9929	0.05119		
Total	119	14.1899			
Grand Mean	2.6096				
CV	8.67				

Appendix 9. Factorial ANOVA table for root length

Factorial ANOVA Table for root length					
Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	1.121	0.5605		
Varieties	9	123.999	13.7776	197.67	0.0000
Sowing	3	85.783	28.5944	410.26	0.0000
Varieties*Sowing	27	46.905	1.7372	24.92	0.0000
Error	78	5.437	0.0697		
Total	119	263.244			
Grand Mean	7.9931				
CV	3.30				

Appendix 10. Factorial ANOVA table for root fresh weight

Factorial ANOVA Table for root fresh weight					
Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	0.3857	0.19287		
Varieties	9	17.4025	1.93361	156.29	0.0000
Sowing	3	5.5324	1.84413	149.06	0.0000
Varieties*Sowing	27	1.2682	0.04697	3.80	0.0000
Error	78	0.9650	0.01237		
Total	119	25.5539			
Grand Mean 2.7678					
CV 4.02					

Appendix 11. Factorial ANOVA table for root dry weight

Factorial ANOVA Table for root dry weight					
Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	0.02255	0.01128		
Varieties	9	0.62245	0.06916	18.79	0.0000
Sowing	3	0.63902	0.21301	57.88	0.0000
Varieties*Sowing	27	0.44369	0.01643	4.47	0.0000
Error	78	0.28705	0.00368		
Total	119	2.01476			
Grand Mean 0.6264					
CV 9.68					

Appendix 12. Factorial ANOVA table for 1st flowering date

Factorial ANOVA Table for 1st flowering date					
Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	0.067	0.0333		
Varieties	9	15.367	1.7074	2.74	0.0078
Sowing	3	100.800	33.6000	53.93	0.0000
Varieties*Sowing	27	37.033	1.3716	2.20	0.0037
Error	78	48.600	0.6231		
Total	119	201.867			
Grand Mean 36.033					
CV 2.19					

Appendix 13. Factorial ANOVA table for 50% flowering date

Factorial ANOVA Table for 50% flowering date					
Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	1.517	0.7583		
Varieties	9	55.300	6.1444	8.80	0.0000
Sowing	3	50.567	16.8556	24.13	0.0000
Varieties*Sowing	27	12.100	0.4481	0.64	0.9022
Error	78	54.483	0.6985		
Total	119	173.967			
Grand Mean	46.683				
CV	1.79				

Appendix 14. Factorial ANOVA table for 1st fruit set

Factorial ANOVA Table	**for 1st fruit set**				
Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	0.817	0.4083		
Varieties	9	42.342	4.7046	2.84	0.0060
Sowing	3	73.558	24.5194	14.80	0.0000
Varieties*Sowing	27	148.692	5.5071	3.33	0.0000
Error	78	129.183	1.6562		
Total	119	394.592			
Grand Mean	57.858				
CV	2.22				

Appendix 15. Factorial ANOVA table for maturity days

Factorial ANOVA Table for maturity days					
Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	13.650	6.8250		
Varieties	9	64.842	7.2046	2.65	0.0097
Sowing	3	203.092	67.6972	24.94	0.0000
Varieties*Sowing	27	89.658	3.3207	1.22	0.2429
Error	78	211.683	2.7139		
Total	119	582.925			
Grand Mean	77.025				
CV	2.14				

Appendix 16. Factorial ANOVA table for number of pods per plant

Factorial ANOVA Table for number of pods per plant					
Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	33.27	16.6333		
Varieties	9	247.71	27.5231	3.32	0.0018
Sowing	3	46.43	15.4750	1.87	0.1422
Varieties*Sowing	27	157.66	5.8392	0.70	0.8463
Error	78	646.73	8.2915		
Total	119	1131.79			
Grand Mean	34.458				
CV	8.36				

Appendix 17. Factorial ANOVA table for number of seed per pod

Factorial ANOVA Table for number of seed per pod					
Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	9.800	4.9000		
Varieties	9	72.467	8.0519	5.11	0.0000
Sowing	3	117.800	39.2667	24.93	0.0000
Varieties*Sowing	27	321.867	11.9210	7.57	0.0000
Error	78	122.867	1.5752		
Total	119	644.800			
Grand Mean	68.400				
CV	1.83				

Appendix 18. Factorial ANOVA table for 1000 seeds weight

Factorial ANOVA Table for 1000 seeds weight					
Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	15.517	7.7583		
Varieties	9	35.033	3.8926	6.63	0.0000
Sowing	3	164.000	54.6667	93.07	0.0000
Varieties*Sowing	27	19.500	0.7222	1.23	0.2380
Error	78	45.817	0.5874		
Total	119	279.867			
Grand Mean	8.1333				
CV	9.42				

Appendix 19. Factorial ANOVA table for yield

Factorial ANOVA Table for yield					
Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	0.00554	0.00277		
Varieties	9	1.40747	0.15639	47.04	0.0000
Sowing	3	0.94004	0.31335	94.25	0.0000
Varieties*Sowing	27	0.36752	0.01361	4.09	0.0000
Error	78	0.25933	0.00332		
Total	119	2.97989			
Grand Mean 0.7223					
CV 7.98					

Plate 4: Field site with signboard.

Plate 5: Different insect that attracted the sesame genotype during experiment

Plate 6: Caterpillar that attracted the sesame leaf during experiment

Plate 7: Identification of disease and pest of sesame genotype

Plate 8: Seeds of sesame genotype