

Legumes : A Study of Waterlogging Tolerance in Gazipur, Bangladesh

Afsana Mimi¹,

1. M.S. Student, Department of Agronomy,
Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur-Bangladesh

Corresponding author e-mail: ddipa21@rediffmail.com

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ABSTRACT

Waterlogging is a serious problem, which affects crop growth and yield in low-lying rainfed areas. Waterlogging of the soil stops air getting in. It reduces the production of dry matter in plant parts; ultimately affect the yield of grain legumes in several parts of the world. The main cause of damage under waterlogging is oxygen deprivation, which affect nutrient and water uptake, so the plants show wilting even when surrounded by excess of water. Flooding often results in leaf chlorosis, defoliation, cessation of growth and plant death. These effects have been widely attributed solely to a lack of oxygen in the root-zone. When tissues are completely submerged and O₂ is exhausted by respiration, complete anoxia may occur. The tolerance of grain legumes to waterlogging may vary between and within species. During initial exposure of legumes under excess water, plants adapted to waterlogged conditions, have mechanisms to cope with this stress such as increase in ethanol fermentation, aerenchyma formation, adventitious roots formation, increased availability of soluble sugars, greater activity of glycolytic pathway, increase of internode elongation rate, maintenance of high carbohydrate concentration, involvement of antioxidant defense mechanism to cope with the post hypoxia/anoxia oxidative stress. No aerenchym is observed in roots of non-flooded plants; however, it is abundant in roots of flooded plants. Aerenchym development is more abundant during vegetative growth stage than reproductive stage. Lower aerenchym formation in reproductive stage may cause lower adaptability in flooded condition. Gaseous plant hormone ethylene plays an important role in modifying plant response to oxygen deficiency. This study investigated the effects of waterlogging and the adaptive mechanisms of crops to tolerance excess water to evaluate the variation in tolerance among grain legume species.

Key words: Legumes; Waterlogging; Hypoxia; Anoxia; Aerenchyma; Adventitious Roo;

Although all higher plants require access to free water, excess water in the root environment of land plants can be injurious or even lethal because it blocks the transfer of oxygen and other gases between the soil and the atmosphere. Crop plants require a free exchange of atmospheric gases for photosynthesis and respiration. Like animals, plants can be easily suffocated if this gas exchange is impeded. The most common impediment to gas diffusion is water that saturates the root environment in poorly drained soils or that accumulates above soil capacity as a result of the overflow of rivers, excessive rainfall or excessive irrigation. waterlogging and submergence are major abiotic stresses. During

waterlogging or submergence plants are exposed to a reduction in oxygen supply because of the slow diffusion rate of oxygen in water and its limited solubility (Armstrong 1978). Growth is greatly inhibited in the deficiency (hypoxia) or complete absence (anoxia) of oxygen.

Food grain legumes are very important as source of protein in many parts of the world in general, and developing countries in particular. However, their productivity is usually low, mainly since they are grown in stressful soil environments. For example, important food grain legumes species, such as, mungbean (*Vigna radiata* L.), soyabean (*Glycine max* L.), common bean

(*Phaseolus vulgaris* L.), chickpea (*Cicer arietinum* L.), fababean (*Vicia faba* L.), cowpea (*Vigna unguiculata* L.), grasspea (*Lathyrus sativus* L.), lentil (*Lens esculentus*), black gram (*Vigna mungo* L.) are usually grown in marginal areas under rainfed conditions and their yields are fairly low (Loss and Siddique, 1997; Frederick et al., 2001; Palta et al., 2004; Thomas et al., 2004; Munoz-Perea et al., 2006; Kashiwagi et al., 2006).

In world, pulses or grain legumes are grown in 69.29 million ha with production of 64.0 million ton and productivity of 924 kg/ha during 2009. India is the largest grower (30% area), producer (23% production) and consumer of pulses.

Food legume crops occupy about 5% of cropped area of Bangladesh but play a significant role in rainfed agriculture. They occupy the second largest cropped area after rice (*Oryza sativa* L.) in the country (5.2% cropped area). The major pulses grown are kheshari, lentil, chickpea, black gram, mungbean and cowpea and they contribute to more than 95% of total pulses production in the country. Others are pigeonpea, pea, fababean, lablab bean, and soybean etc.

Waterlogging is an obstacle in legume cultivation. The extent of waterlogging has already thrown a serious challenge for sustainability of irrigated agriculture in irrigation commands. Flat and saucer shaped topography of land, high rainfall, and inadequate drainage often lead to waterlogging in irrigation commands. Water logging caused by rise in ground water is also responsible for lowering of land productivity in many areas. Water logging may be natural or may be due to faulty irrigation management. About 8000 hectares of waterlogged land occurs in Khulna- Jessore area (popularly known as Beel Dakatia). This is an example of human induced land degradation caused by faulty construction of embankment.

The soil and crop environment is affected by excess water through the depletion of oxygen, leading to reduced root respiration and other vital plant processes, as well as the production and accumulation of phytotoxic compounds, such as ethylene, in plant roots and soil. Saturated soil conditions change the soil's redox potential, favouring loss of nitrogen and production of ions that are toxic under certain soil conditions. These factors combine to hamper plant growth and cause significant yield losses. Crop performance under such stress

conditions is closely related to root system development. In this regards, knowledge of root characteristics is required agronomically to select suitable crop species to be grown in a particular environment. Grain yield decrease is greater when they flooded in reproductive stage rather than flooded in vegetative stage (Oosterhuis et al., 1990; Scott et al., 1990).

A common response of wetland plants to waterlogging is the formation of an adventitious root system. These stem-borne roots can stay suspended in the water column, or grow down into the sediment. Adventitious roots are adapted to the flooded environment and may support or replace the primary root system (Jackson and Drew, 1984). As a flooding response, the growth and physiology of aquatic roots produced by woody perennials have received some attention (Hook et al., 1970; Gomes and Kozlowski, 1980; Islam and Macdonald, 2004; Iwanaga and Yamamoto, 2008; Rich et al., 2008). Plants use various mechanisms to adapt the hostile environment of waterlogged soils and to submergence of shoots during floods. Anatomical and morphological adaptations in roots, shoots and stems allow ventilation of submerged organs and lessen or even avoid the impact of water logging and flooding. The objectives of the study are:

- i. To highlight the effects of waterlogging on growth and yield of grain legumes
- ii. To highlight the mechanisms of waterlogging tolerance in grain legumes and
- iii. To review the genotypic variation in tolerance to waterlogging in grain legumes.

Table 1. Current Trends in Acreage and Production of Pulse Crops

Crop	Area (ha)	Production (ton)	Yield (ton/ha)
Lentil	82996	80000	0.97
Grasspea	89474	83000	0.93
Mungbean	27530	19000	0.69
Blackgram	31579	29000	0.92
Chickpea	8097	7000	0.87
Others	6883	6000	0.88
Total	246559	224000	5.26

Source: BBS, 2012

Present status of legumes in Bangladesh: Bangladesh is a flood-prone country where flood is a year-wise natural phenomenon. During flooding especially southern

part of our country greatly face waterlogging situation. Though rice is our staple food, now we are growing pulse crops to meet demand of our increasing population. Varieties of pulses are grown and consumed in Bangladesh over several millennia. It varies from year to year (Table 1) and location to location.

Protein Contribution of Legume Crops: Pulses have been considered “Poor Men’s Meat” since they are the cheapest source of protein for the underprivileged people who cannot afford expensive animal proteins. Not only have pulses twice the protein content of cereals, they contain more protein on weight to weight basis than eggs, fish and red meats. Besides higher protein content (Table 2), they also contain other essential elements, minerals etc. for our body.

Table 2. Protein Content of Legumes (as % of Dry Matter)

Legumes	Protein Content(%)
Chickpea (Gram)	21%
Pegionpea (Arhar)	22.3%
Blackgram	24%
Mungbean	24%
Lentil	25.2%

Source: (Panda, 2005)

Demand and Supply of Pulses in Bangladesh: The demand and supply of the pulses need to be seen from the angle of food balance of the population. According to the National accounting wing of the BBS reported that in 2004-05 there was 2484Kcal protein consumption. The calorie from carbohydrate source was 84.27% in 2004-5 as against standard need of 60-65%.

On the other hand, protein and fat sources should supply within the range of 15-20 and 20-25% respectively. Based on these discussions the demand for protein and edible fats and oils has been identified for 2007-8. By 2008-9 the total demand for pulse grains is about 6 times of its present supply from both local production and import.

Though pulses are regarded as minor crops of Bangladesh, their requirement is gradually increasing among the growing population. Because of their easy accessibility and relatively lower input cost and management practices of cultivation, their demand is increasing (Table 3).

Some programs have been projected for seed

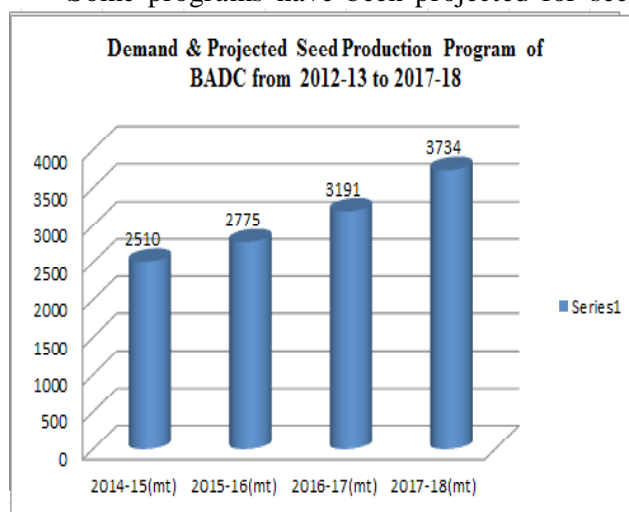


Figure 2: Demand and Projected Seed Production Program of BADC from 2012-13 to 2017-18 (Source: BADC, Annual

Production Share of Pulses: The yield and production

Table 3. Demand / Requirement of Quality Seeds of Pulse

Crops	Demand	Distribution (MT) in Years				Projected
		2005-06	2006-07	2007-08	2008-09	
Pulses	21,370 100%	245 1.14%	1612 7.54%	2808 13.13%	3103 14.52%	4710 22.04%

Source: Bangladesh Seed Conference & Exhibition 2008 and 2009. Seed Wing, Ministry of Agriculture. (BBS, 2009)

Table 4. Breeder Seed demand (Kg) from BADC & Supply from Different Organizations for Pulses Varieties from 2006-07 to 2008-09 (Source: BADC, 2011)

Crops	2006-07		2007-08		2008-09		Average
	Demand	Supply	Demand	Supply	Demand	Supply	
Pulses							
Lentil	2280	2100	6880	2080	3636	3396	2525
Grass Pea	800	800	1560	440	1100	935	725
Gram	746	736	962	902	720	690	776
Mung	2932	2888	4304	4304	3430	3329	3507
Blackgram	760	680	1012	1012	740	730	807
Total	7518	6840	14718	8738	9626	9080	8340
% supply	100%	90.98%	100%	59.37%	100%	94.32%	81.55%

of different pulses varies greatly due to their demand, supply, and utility. Dry bean, Pea and Chickpea show higher production share among all pulses (Table 6, Figure 3).

Table 6: Production share of pulses (Source: FAOSTAT)

Pulses	Share%
Dry Beans	34%
Lentils	5%
Chickpea	13%
Dry Pea	19%
Dry Broad Bean	7%
Cow Pea	7%
Pegion Pea	5%
Lupins	2%
Others	8%

Effect of Legumes on Soil Quality: Legumes have long been recognized and valued as “soil building” crops. Growing legumes improves soil quality through their beneficial effects on soil biological, chemical and physical conditions. When properly managed, legumes will:

- enhance the N-supplying power of soils
- increase the soil reserves of organic matter
- stimulate soil biological activity
- improve soil structure
- reduce soil erosion by wind and water
- increase soil aeration
- improve soil water-holding capacity
- make the soil easier to till

Probable Causes of Waterlogging:

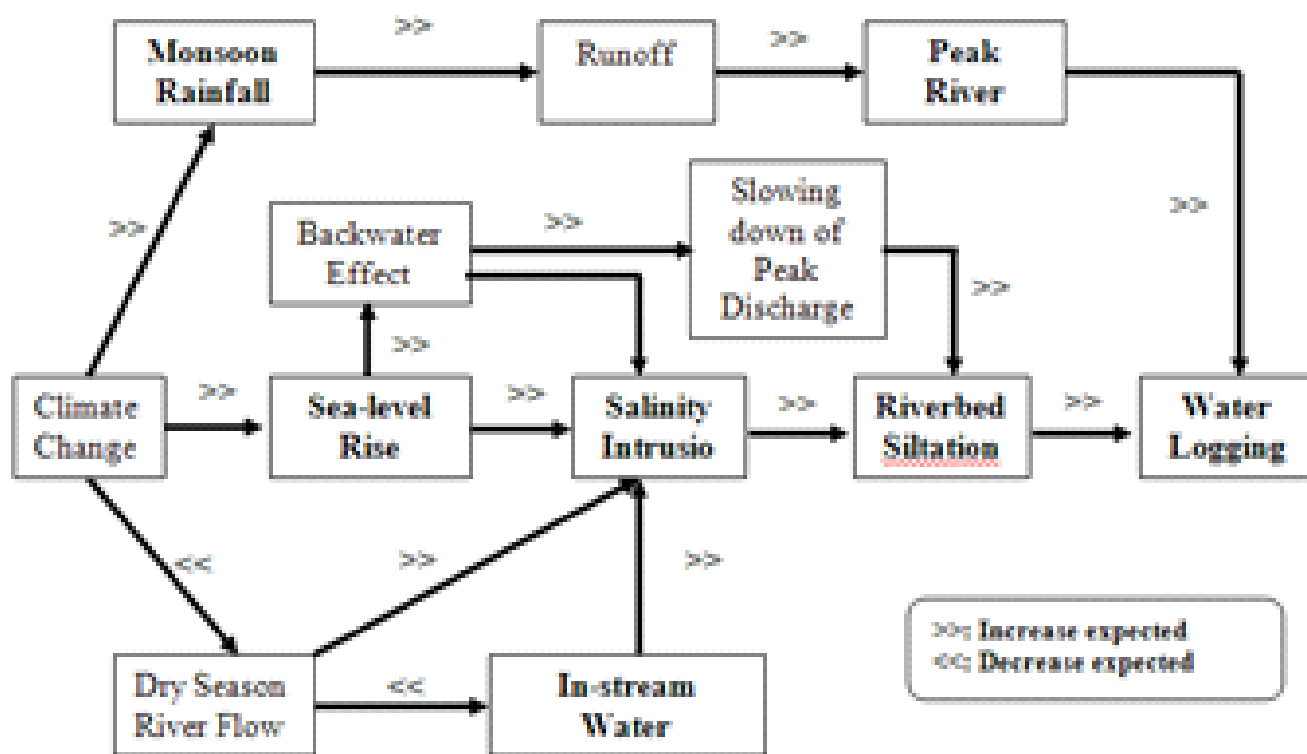


Figure 4: Schematic Representation of Various Cause-Effect Relationships Towards Increasing Waterlogging Under Climate Chang (Source: Ahmed et al., 2007)

Effect of water logging on the soil: Water-logging can also indirectly impact plants growth by affecting the availability of nitrogen in the soil. Excessive water can cause leaching of nitrate nitrogen beyond the rooting zone of the developing plant, particularly in lighter textured soils. Furthermore, when oxygen levels become depleted, soil microbes extract oxygen from the nitrate

molecule, causing nitrogen to be converted to a gaseous form that is lost to the air (denitrification).

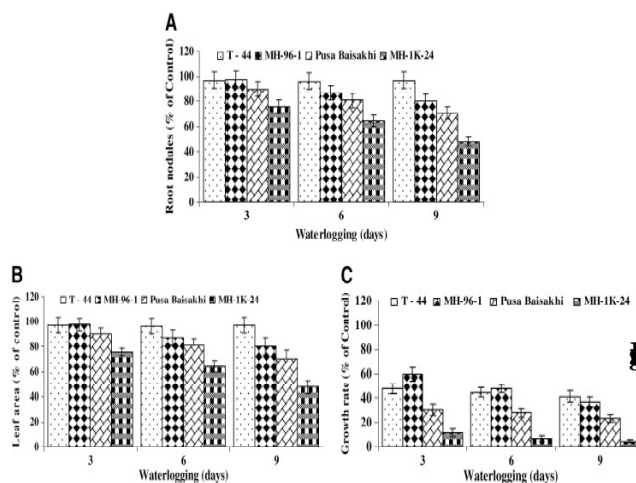
Effect of Waterlogging in Some Cultivated Legume (Pulses) Crops: There are several factors that influence the magnitude of excess water stress has on growing crops, including: soil type, plant species, plant growth stage, temperature, day length and duration of the stress.

Grain legumes are highly sensitive to excess water affecting days to flowering, days to maturity, plant height, pods/plant, seed yield and straw biomass. However, grain legume crops can withstand short period of waterlogging. Under conditions of excess water, it is the lack of oxygen (O_2) that changes the soil and crop environment. Oxygen diffuses in water 10000 times more slowly than in air, resulting in changes in nutrient availability and microbial activity, reduced plant respiration and energy production and the accumulation of compounds in roots and soil that may become toxic to plants. Like oxygen, carbon dioxide (CO_2) and ethylene (C_2H_4) gases diffuse more slowly through water than through air, and accumulate around plant roots as a result. Ethylene is a root growth inhibitor with varying effects on different crops.

Mungbean (VignaradiataL) :

Effects on Plant Growth : Waterlogging caused yellowing of leave and reduced the plant growth of all genotypes, however, reduction was significantly lower in tolerant genotypes (T- 44 and MH-96-1) compared to sensitive

higher root nodules per plant than sensitive genotypes under waterlogging (Figure 6A) and maintained significantly higher leaf area(Figure6B) and growth rate under waterlogging compared with sensitive genotypes (Figure 6C).



6:Effect of waterlogging on A. root nodule/plant growth rate, B. leaf area and C. growth rate in tolerant (T-44 & MH-96-1) and susceptible (Pusa Baisakhi and MH-1K-24) genotypes of mungbean (Source: Kumar et al.,2012)

Effects on Chlorophyll Content: Under waterlogging, all genotypes showed chlorosis and yellowing of leaves and reduction in photosynthetic pigments (Figure 7). However, sensitive genotypes (Pusa Baisakhi and MH-1K-24) exhibited relatively higher chlorosis and drastic reduction in the level of chlorophylls as compared to tolerant ones viz. T 44 and MH- 96-1. The level of photosynthetic pigments reduced with increasing level of waterlogging. Amongst all the genotypes, T 44 maintained the highest levels of total chlorophylls under waterlogging. Both the sensitive genotypes showed drastic reduction in the levels of total chlorophylls under waterlogging.

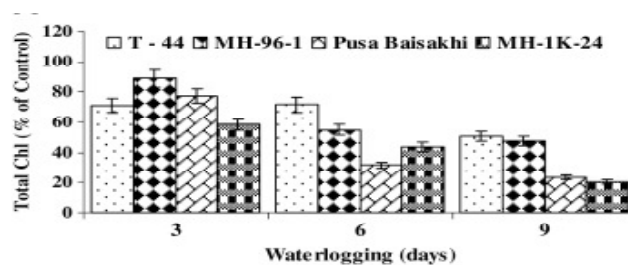


Figure 5:Growth of four contrasting tolerant (T-44 & MH96-1) and sensitive (Pusabasakhi& MH 1K – 24) genotypes of mungbean after 9 days of waterlogging (Source: Kumar et al.,2012)

Effects on Nodulation: Tolerant genotypes maintained

Figure 7: Effect of waterlogging on a total chlorophyll

content in leaf tissues of tolerant (T-44 & MH-96-1) and sensitive (Pusa Baisakhi and MH-1K-24) genotypes of mungbean (Source: Kumar et al.,2012)

Effects on Total Dry Matter Production and Dry Matter Partitioning: Waterlogging in mungbean reduced total dry matter production and also affected the dry matter partitioning (Figure 8). Relative reduction in dry matter was more pronounced in sensitive genotypes than tolerant ones. At harvest, under waterlogged condition tolerant genotypes i.e. T- 44 and MH- 96-1 exhibited relatively higher dry matter accumulation in root and slight reduction in stem and leaf over its control (Figure 8A-D). However, waterlogging sensitive genotypes Pusa Baisakhi and MH-1K-24 showed poor dry matter accumulation in root and higher dry matter accumulation in stem and leaf under waterlogging than its control (Figure 8E-H). In T- 44, proportion of dry matter partitioning in pod under waterlogging remained exactly similar to its control and very slightly reduced in MH- 96-1 (Figure 8A-D). However, in sensitive mung bean genotypes Pusa Baisakhi and MH-1K-24, proportion of dry matter partitioning in pod under waterlogging was recorded lower than their respective controls (Figure 8E-H).

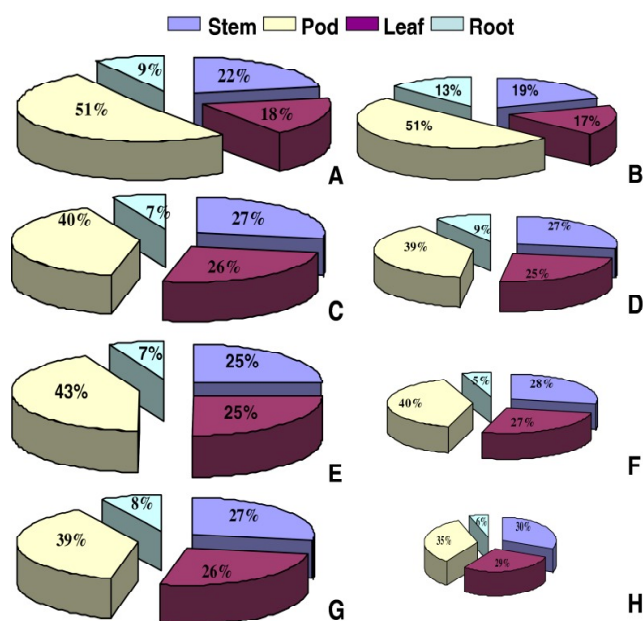


Figure 8: Dry matter partitioning in leaves, stem, roots and pods in tolerant (T-44 & MH 96-1) and sensitive (Pusa Baisakhi & MH-1K 24) mung bean genotypes under control and waterlogged conditions.

- (A) T-44 (control),
- (B) T-44 (waterlogged),
- (C) MH 96-1(control),
- (D) MH 96-1(waterlogged),
- (E) Pusa Baisakhi(control),
- (F) Pusa Baisakhi(waterlogged),
- (G) MH-1K 24(control),
- (H) MH-1K 24(waterlogged) (Source: Kumar et al.,2012)

Effect on Flowering and Podding Patterns : Both tolerant and sensitive genotypes showed the inhibition of flowering, pod setting and enhanced the dropping of flowers and pods under waterlogging (Figure 9A-H). However, number of floral buds and pods per plant were most affected under waterlogging only in sensitive genotypes (Figure 9E-H). There was severe reduction in pod setting in sensitive genotypes viz. Pusa Baisakhi & MH-1K-24 and this reduction was mainly associated with the dropping of floral buds and pods (Figure 9E-H). In contrast, tolerant genotypes T- 44 and MH-96 - 1 maintained fairly good pod setting even in waterlogged plant (Figure 9A-D).

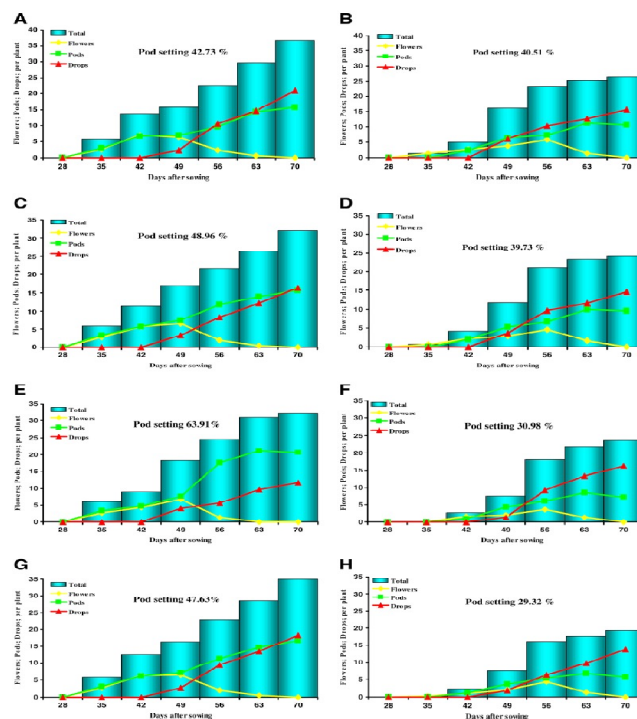


Figure 9: Comparative account of flowering, podding and droppings patterns in tolerant (T-44 & MH 96-1) and sensitive (Pusa Baisakhi & MH-1K 24) genotypes under control and waterlogging. A T-44 (control), B T-44 (waterlogged), C MH

96-1(control), **D** MH 96-1(waterlogged), **E** Pusa Baisakhi(control), **F** Pusa Baisakhi(waterlogged), **G** MH-1K 24(control), **H** MH-1K 24(waterlogged) (Source: Kumar et al.2012)

Effects on Yield : The yield was affected by waterlogging in all the genotypes. Yield losses increased with the increase in waterlogging duration at vegetative stage. On an average, grain yield losses in all four mung bean genotypes at 3, 6 and 9 days of waterlogging were 20.01, 33.79 and 51.88 %, respectively. Tolerant genotypes almost recovered the grain yield losses caused by 3 days waterlogging. However, for sensitive genotypes even 3 days waterlogging reduced the yield upto 20 %. Grain yield losses in sensitive genotypes after 9 days waterlogging at were estimated 70.0 (Pusa Baisakhi) to 84.9 % (MH – 1K – 24) as compared to their respective controls. Tolerant genotypes showed comparatively lesser yield reduction even after 9 days of waterlogging (Figure 10).

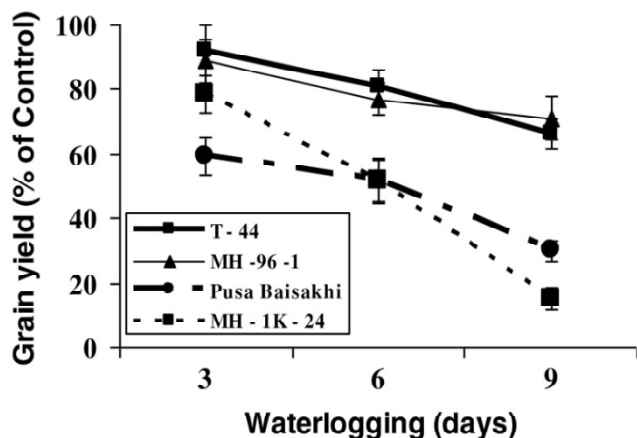


Figure 10: Relative reduction in grain yield of mungbean tolerant (T-44 & MH 96-1) and sensitive (Pusa Baisakhi & MH-1K 24) genotypes under varying durations of waterlogging at vegetative stage. Genotype wise control average values of grain yield (Kumar et al.,2012).

From Islam, 2003, Plant height decreased linearly with increasing duration of flooding at flowering and pod-filling stages but it tends to increase at vegetative stage. There was variation in plant height due to genotypes. Height of GK 48 was significantly higher than two others. Branches/plant, Pod/plant etc. were also higher in GK 48. Flooding significantly reduced 100 seed weight when flooding period extended up to & days particularly at flowering stage, but flooding at pod-fill stage did not affect seed weight. It is probable that

re-growth of plant occurred at flowering stage and plants produced some pods but due to poor source sink relationship seed weight significantly reduced (Table7). A complete crop failure due to soil flooding is not uncommon. Mungbean is somewhat tolerant to deficit water but susceptible to excess water.

Table 7. Effect of Flooding Duration on Yield Attributes of Three Mungbean Genotypes at Different Growth Stages

1	2	3	4	5	6
Control	59.40	4.33	58.86	8.19	4.85
Vegetative Stage					
1 Day	57.90	3.81	58.71	8.67	4.32
3 Days	58.90	4.24	51.19	8.35	4.51
7 Days	61.95	4.48	46.86	8.58	4.38
Flowering Stage					
1 Day	55.71	4.29	60.95	8.42	4.40
3 Days	52.74	4.48	53.38	8.30	4.53
7 Days	51.84	4.62	45.38	7.52	4.03
Pod Filling Stage					
1 Day	62.21	3.95	58.38	8.53	4.82
3 Days	58.81	3.91	26.62	8.52	4.50
7 Days	56.49	3.81	21.71	8.20	4.74
Genotypes					
GK48	65.38	3.81	57.86	8.44	3.75
VC3945A	53.06	3.43	44.27	8.14	5.59
Vo1982A-G	54.34	5.33	45.66	8.40	4.18

1=Flooding Treatments, 2=Plant Height at Maturity(cm), 3=Branches/Plant(no.), 4=Pod/Plant(no.), 5=Seed/Pod(no.), 6=100 Seed Weight (g)

Source: (Islam.2003)

Field Pea (*Pisumsativum*): Cannell et al. (1979) reported that waterlogging for only one day or more before flowering restricted growth and yield of peas, but this effect was less marked at earlier and later stages of plant development. Water logging effects are also seen in pea (Table 8) in different stage-

Table 8. Effect of Water Stress on Pea

Treatment	Relative Yield
Control(Non-flooded)	100%
Waterlogged for 5 days	
@4-5 Leaves stage	48%
@6-7 Leaves(Pre-flowering)	7%
@9-10 Leaves(Flowering)	25%
@Pod Filling	42%

Source: (Cannell et al,1979)

Table 9. Effects of Waterlogging on the Stem Characteristics of Soybean

Growing Period	Duration (Days)	Stem Length(cm)	StemWeight(g)	Branches/Plant	Nodes/Plant	Pods/Node
Control	0	56.0	12.10	9.50	53.67	2.01
Flower Bud	3	53.9	10.06	9.60	55.20	1.97
Differentiation	6	54.6	10.55	7.83	53.50	1.82
	10	53.8	8.93	8.33	51.00	1.91
	20	53.4	8.13	7.33	41.20	1.86
	30	53.3	8.50	6.50	43.50	1.48
	M	52.5	8.23	7.17	42.50	1.39
Ripening	3	54.7	11.45	9.50	55.83	1.89
	6	56.4	11.96	10.20	52.44	1.98
	10	55.3	11.60	10.60	54.60	1.89
	20	57.3	11.78	10.40	56.20	1.87
	30	55.4	11.50	9.20	52.60	1.89
	M	54.2	11.43	9.17	53.00	1.89

Source: Sugimoto et al.,2000, M= Treatment Until Maturity

Soybean (*Glycine max L.*): Waterlogging is a major problem that reduces soybean (*Glycine max L.*) growth (Table 9) and grain yield in many areas of the world. Photosynthesis of soybean cultivars is reduced under the waterlogging condition, also is recovered after flooding in vegetative stage while flooding in flowering stage cause severe damage on soybean plants. No aerenchyma was observed in roots of non-flooded plants; however, it was abundant in roots of flooded plants.



Figure 11: Waterlogging Injury in Soybean Plants (Cornenous et al., 2005)

Adaptive Mechanisms of Legume Crops under Waterlogging Condition: What mechanisms do plants use to adapt to the hostile environment of waterlogged soils and to submergence of shoots during floods? Anatomical and morphological adaptations in roots, shoots and stems allow ventilation of submerged organs and lessen or even avoid the impact of waterlogging and flooding.

Anatomical Adaptations (Ethylene and Aerenchyma Formation): Ethylene initiates and regulates many adaptive molecular chemical and morphological responses that allow the plant to avoid anaerobiosis by increasing oxygen availability to the roots in a flooded or waterlogged soil, such as development of aerenchyma. Aerenchyma are soft tissues with large intercellular spaces to provide low resistance internal pathway for the exchange of gases between aerobic shoot to the anaerobic root (Jackson and Armstrong 1999).

O₂ transport from shoots to roots in waterlogged soils, giving quantitative arguments for internal ventilation as a factor in flood tolerance. Adequate supply of O₂ to submerged organs requires enhanced development of internal gas spaces, principally by formation of large interconnected lacuna called aerenchym. Aerenchyma development is more abundant during vegetative growth stage than reproductive stage. Lower aerenchyma formation in reproductive stage may cause lower adaptability in flooded condition. O₂ is transported to flooded roots through the aerenchyma and is consumed by root respiration in intact soybean plants (Shimamura et al., 2010). Although aerenchyma forms rapidly in the hypocotyls in response to flooding stress (Shimamura et al., 2003), the development of a network of secondary aerenchyma in the flooded roots requires a few weeks of flooding (Shimamura et al., 2003; Thomas et al., 2005), during which period the (soybean) plants are injured by an oxygen shortage.

Therefore, to improve the flooding tolerance of soybean, it will be necessary to investigate not only the potential for the transportation of oxygen via the aerenchyma, but also the rate of development of a network of aerenchyma in flood-tolerant legumes. Waterlogged soybean plants form aerenchyma in the

base of the stem, adventitious roots (*Becanamwo and Purcell, 1999a; Pires et al., 2002; Shimamura et al., 2003*), taproot (*Shimamura et al., 2003*), lateral roots (*Bacanamwo and Purcell, 1999a*) and in nodules (*Pankhurst and Sprent, 1975; Shimamura et al., 2003*).

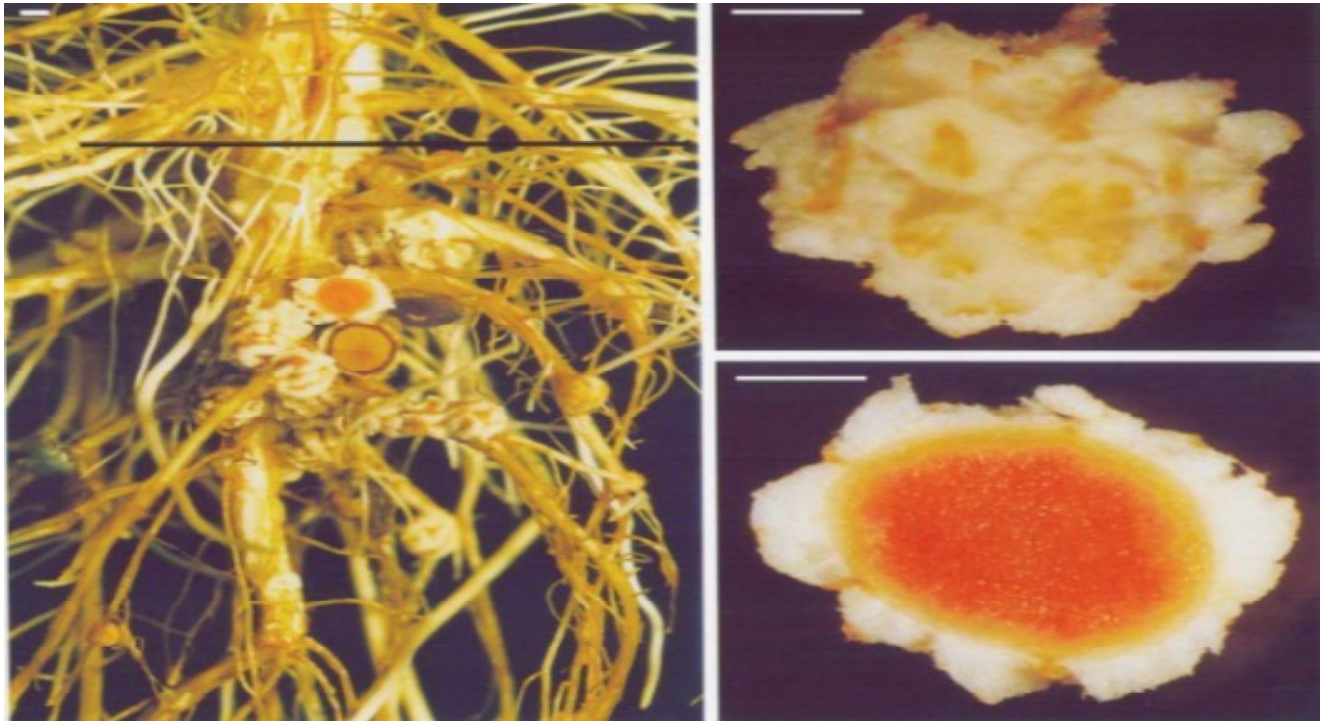


Figure 12: Soybean plants Subjected to Waterlogging -Nodule in Root System with External and Internal View (Source: *Thomas et al., 2005*)

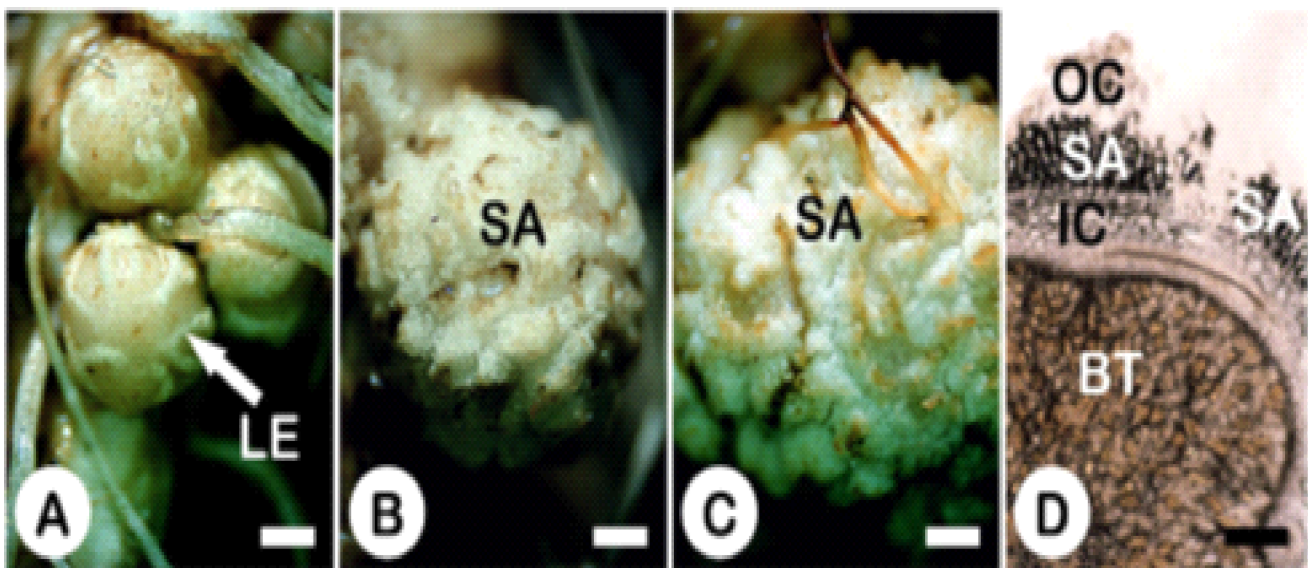


Figure 13: External and internal structures of the root nodules of flooded soybean plants. Root nodules showing lenticels and secondary aerenchyma development after (A) 1, (B) 2, and (C) 4 weeks of flooding (*Shimamura et al., 2002*)

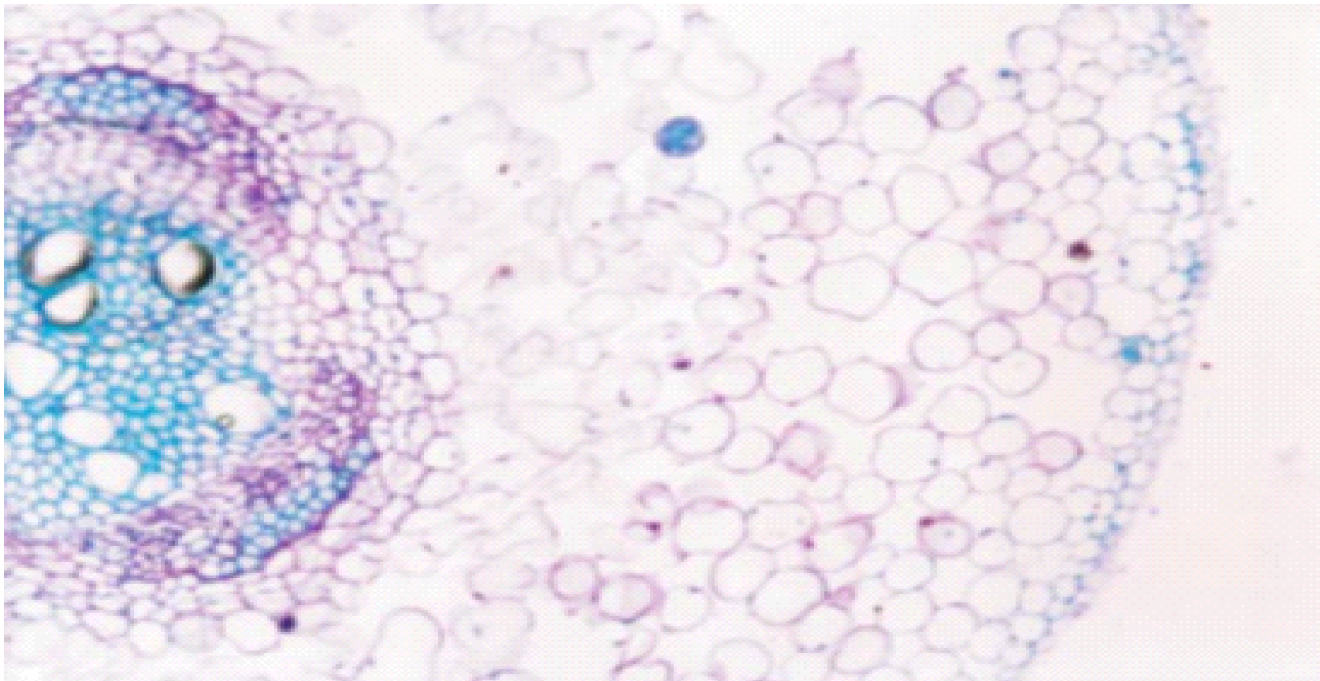


Figure 14: Transverse Section of Aerenchyma in Adventitious Root in Soybean During Flooding (Thomas *et al.*, 2005)

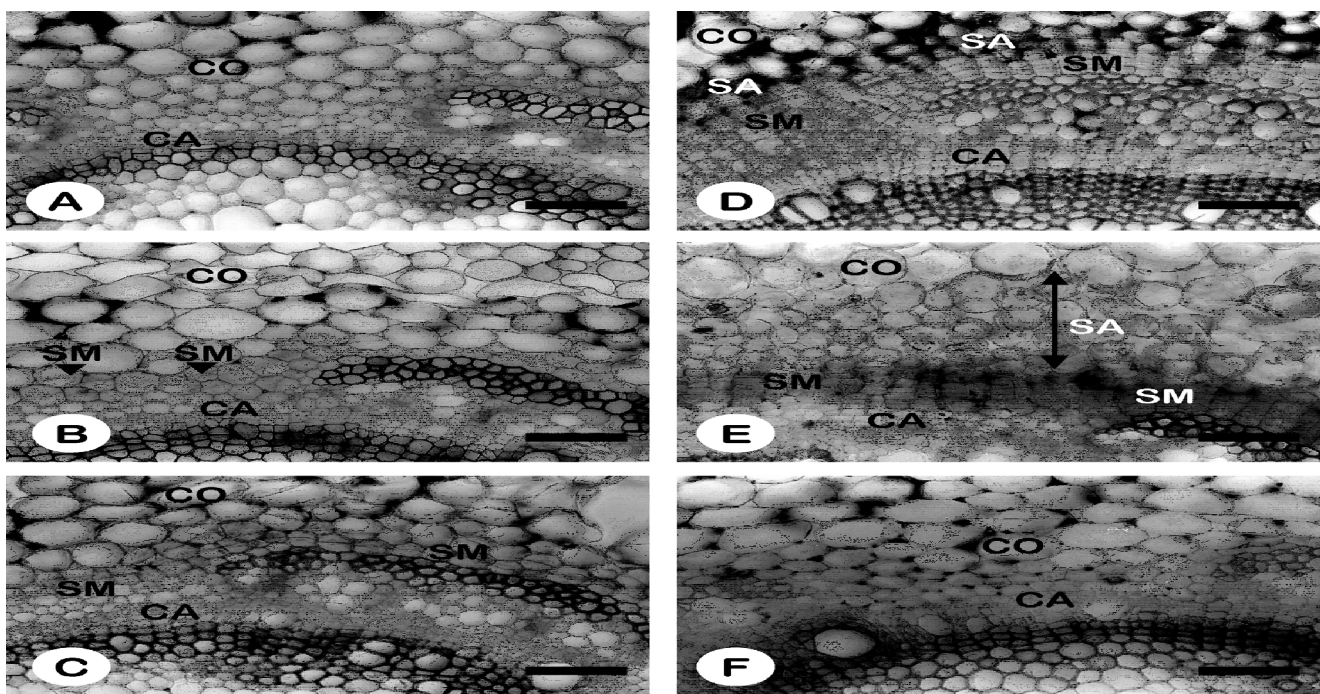


Figure 15: Processes involved in secondary aerenchyma formation in the hypocotyl of soybean. (A) After 1 day, (B) after 1.5 days, (C) after 2 days, (D) after 3 days, (E) after 4 days of Flooding, and (F) after 4 days of irrigation (but with aerobic soil conditions maintained). CA, cambium; CO, cortex; SA, secondary aerenchyma; SM, secondary meristem (Shimamura *et al.*, 2003)

Morphological Adaptations (Adventitious Root Formation): Adventitious roots emerge from the submerged part of the stem in flooded plants and grow horizontally. Presumably, this is also an

adaptive mechanism allowing these new roots to replace the function of the original root system (Jackson and Drew 1984). Since these roots emerge and grow close to the water surface, and since they are connected to

the stem close to the site of aerenchyma formation, oxygen is more available to these roots than the original root system.

In addition to anatomical adaptations, plants can adapt morphologically to mitigate O_2 deprivation during waterlogging or submergence. For example, fine surface roots proliferate in response to waterlogging in both dryland species (e.g. pea) and marsh plants (e.g. *Melaleuca* spp.). These surface roots benefit from a thin aerobic layer at the surface of waterlogged soil. Fine roots can use their large surface area to volume ratio to scavenge O_2 effectively from surface water, at the same time generating energy for nutrient acquisition from this enriched zone. These newly emerged surface supporting roots are called “Adventitious Root” (Figure 16 & 17).

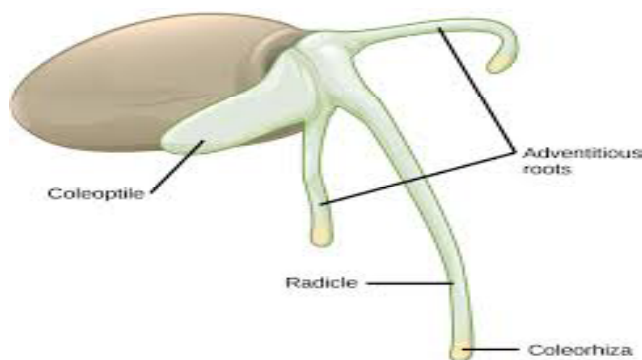


Figure 16: Adventitious Root Development in Waterlogging

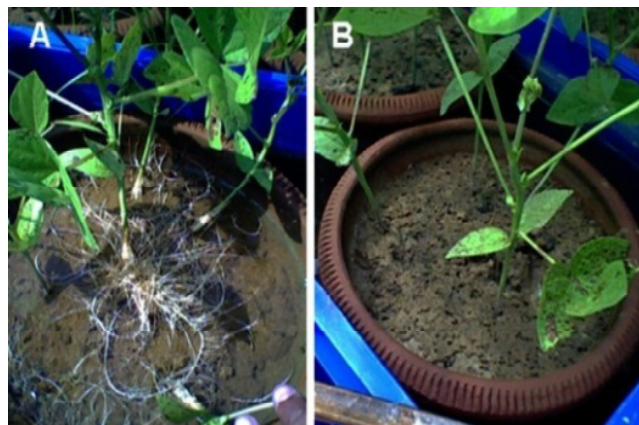


Figure 17: Root growth is affected under waterlogging and tolerant genotypes showed formation of horizontal adventitious roots (A) at soil surface from the transition zone between root and shoot (Source: Kumar et al., 2012)

Flooding greatly increased adventitious root development (Figure 17). Adventitious roots are completely absent in non-flooded plants.



Figure 18: Change of root morphology after flooding treatment (Adventitious Root Formation)

Metabolic Adaptations: Plant adaptation to O_2 -deficient environments involves the anatomical and morphological changes outlined above which allow ventilation of submerged parts. However, metabolic responses to anoxia are essential if particular cells like root apices are to survive. Ethanol production and lactate removal would avoid dangerous acidification of cytoplasm in waterlogging condition. During anoxia, normal protein synthesis is replaced by the selective transcription and translation of a set of proteins called ‘anaerobic’ proteins.

Pictorial View of Some Legume Crops in Bangladesh



Fig 19: Grasspea Plant, Flower and Pod



Fig 20: Mungbean Plant, Flower, Pod and Grain

Fig 21: Blackgram Pod

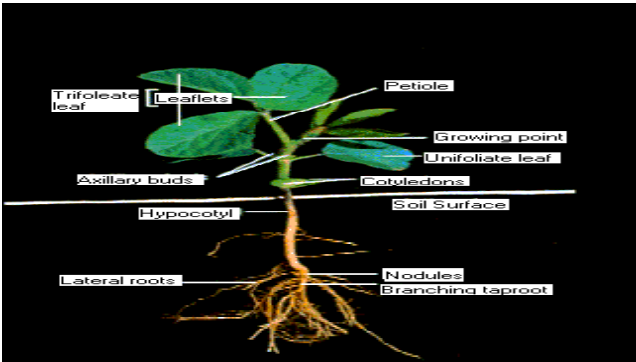
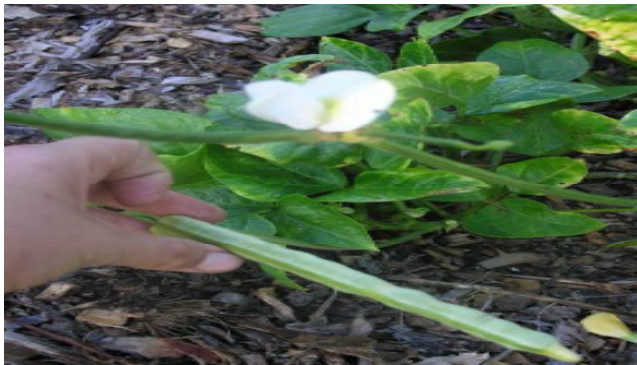


Fig22: BushbeanPod and Flower
Fig 23: Chickpea
Fig 24: Pea, Fig 25: Soybean Plant and Flower

Fig 26: Lentil Fig 27: Pigion Pea

Future Challenges and Requirement of Pulses:

- Growing demand for food and nutrition
- Inadequate research priority: many species, and some still to be explored and utilized
- Declining productivity of landraces (eg soybean and blackgram)
- Climate change: shortening growing period (winter legumes), severe drought, high risk in crop production
- Pests, diseases, weeds, soil nutrients (micronutrients)
- Multiple pickings (mungbean, cowpea)
- Genotype x Environment interaction (varieties for specific production zones)
- Unavailability of quality seed/ lack of systematized seed supply system
- Imbalanced use of fertilizers

Source: (FAOSTAT, 2011)

Future Outlooks for Enhancing Pulse Production in South Asia: Grain legumes play an important role in nutritional security of poor rural population. Also, there is a good scope as an export commodity (lentil as whole/ split seed as dal) or to improve utilization of plant protein by diversifying products. This also generates employment thereby increase income. However, grain legumes research have not received adequate institutional support for yield improvement as they are always considered secondary importance and grown in marginal lands with minimum or no inputs. Commercialization of high valued legumes such as lentil, mungbean, chickpea, pea etc. by improving access

offarmers to improved seeds, fertilizers, supplemental irrigation, better postharvest management and marketing are the present needs in increasing production and productivity.

CONCLUSION

Excess water is a serious problem in low-laying rainfed areas. Lack of oxygen supply for the plant is the main reason of damage in water logging condition, which hampers nutrient and water uptake, as a reason the plant shows wilting. Their growth, dry weight, chlorophyll content reduce; ultimately yield reduction occurs.

The observed morphological and anatomical changes concerning the formation of adventitious roots and aerenchyma formation that occurred in the submerged roots as adaptive mechanisms of legumes in waterlogged situation. But these changes were not enough to fully adapt to waterlogged condition.

Plants which can withstand waterlogging condition have mechanisms such as increased availability of aerenchyma formation, greater activity of glycolytic pathway and fermentation enzymes, and involvement of adventitious root formation to cope with the oxidative stress induced by water logging. Ethylene plays an important role in change of mechanisms of plants in deficiency of oxygen. The ability of adaptation was different between genotypes and also with different growing stages. Grain yield decrease is greater when they flooded in reproductive stage rather than flooded in vegetative stage. By developing of varieties tolerant to excess soil moisture might be an option for increasing yield and sustainability of legume production.

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