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Review Article

Waterlogging In Cotton: Stress, Consequences, Adaptability, Mechanisms and Measures for Mitigation of Yield Losses

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ABSTRACT

From many years, global cotton production suffers from waterlogging stress. Climatic variation and heavy rainfall conditions with poor internal soil drainage mechanism limits the growth and development of cotton crop due to waterlogging. It reduced the soil oxygen which causes the severe yield losses and sometimes even failure of a crop. Indeterminate growth habit of cotton plant makes it able to adapt this stress by activation of the escape, self compensation and quiescence mechanism. The reduction of biomass, development of adventitious roots and accelerated growth mechanism, all are associated with adaption and tolerance mechanisms. Waterlogging significantly affect the cellulose and sucrose content of fiber in cotton. Sodic soils also exacerbate the waterlogging stress because these soils already suffer by aeration stress. Different growth stages are effect differently but flowering and boll setting stage is more sensitive to waterlogging conditions.

Keywords: *Cotton, Crop, Fiber, Biomass*

INTRODUCTION

Waterlogging is considered as major problem in cotton (*Gossypium hirsutum L.*) production worldwide (Gillham et al., 1995). Changing climatic conditions, waterlogging, flooding and inadequate drainage of the land adversely affect the fiber quality and yield of cotton crop. Fiber quality (strength, ability of dyeing and maturity) is directly related to the cellulose content of the plant (Triplett, 1993). Flooding, submergence and waterlogging stress are generally interlined with each other. In poor environmental conditions plant experience the shortage of oxygen supply, low intensity of light, susceptibility to many fungal diseases and losses in nutrient uptake efficiency of plant (Nishiuchi et al., 2012), (Ram et al., 1999). Under waterlogged conditions hypoxia and anoxia takes place. Hypoxia is a condition in which the oxygen level of soil falls below the optimal level (Ahmed et al., 2013), which rises the soil temperature and accelerate the respiration activity.

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It inhibits or lowers the aerobic respiration, nutrient acquisition and generation of energy (Jackson & Drevo, 1984). Anoxia is the condition of complete deprivation of oxygen and rate of diffusion 10,000 times lower in waterlogged than well-drained soils (Hossain & Uddin, 2011). Decrease in oxygen level increase the carbon dioxide concentration and ethylene concentration as well (Wiengweera & Greenway, 2004). Cotton is poorly adaptable to waterlogging stress that's why the severe affects on growth, development and nutrient uptake efficiency causes ultimate yield losses (Dood et al., 2013), (Wang et al., 2012), (Bange et al., 2004), (Hocking et al., 1987).

Plants undergo various anatomical, physiological, morphological, biological and metabolic changes in their activities for survival under stress environment.

2. Waterlogging Effect in Cotton

Waterlogging causes the hypoxic stress which shows the detrimental effects on the root growth of cotton plant which prone plant more towards lodging. Energy metabolism is changes from aerobic to anaerobic respiration, carbohydrate imbalance and reduction in plant growth and development. In severe conditions causes leaf senescence, yield losses or even death of a plant.

i. Photosynthesis Mechanism

Waterlogging stress causes the decrease in photosynthesis which leads to yield loss (Li et al., 2011). Premature senescence occurs when the rate of chlorophyll content is significantly decreased (Dong et al., 2003), (Pandey et al., 2001). Photosynthetic rate is significantly dropped after waterlogging in cotton crop for 72 hours (Milroy & Bange, 2013). Chlorophyll content is reduced to 8.9% after 3 days of waterlogged land conditions and 11.5% and 17.2% under submersion condition for 3 to 12 days (Liu et al., 2010). Leaf thylakoid stability reduced by flooding (Luo et al., 2008). Leaf chlorophyll content is decreased and causes the stomatal closure under waterlogging (Yordanova et al., 2005), (Bradford, 1983). Waterlogging stress lowers the water potential of leaf, rate of transpiration and stomatal conductance (Meyer, 1987).

ii. Cotton Plant, Nitrogen and Carbon Metabolism

In cotton protein content and soluble sugar concentration because of waterlogging changes which disrupt the balance of carbon C and nitrogen N metabolism. Song et al., 2012 proposed that 10.3% decrease in soluble protein and 14.1% in Bt protein content and there is 8.5% increase in soluble sugar content due to waterlogging. It is noted that imbalance in C and N metabolism of cotton is not only due to stress but also due to adaptation mechanism.

iii. Cell Membrane System of Cotton

When the plant under abiotic stress i.e.: waterlogging (Meyer et al., 1987) which causes oxidative damage, usually leads to increase in active oxygen generation (Liu et al., 2010). With increased lipid peroxidation due to stress damage the cell membrane of plant cells. Guo et al. 2010 explained in his studies that malondialdehyde (MDA) is a major indicator of damage of cell membrane which further leads to series of negative biochemical and physiological events. At flowering and boll setting stage after 8 days of waterlogging stress is increase in MDA content from 12.8 to 93.1% in roots of cotton plant.

iv. Nutrition Efficiency of Plant

Inhibition in uptake of essential nutrients like calcium (Ca), phosphorus (P), nitrogen (N), potassium (K), magnesium (Mg) takes place due to waterlogging in cotton (Smethurst et al., 2005). Nutrient uptake efficiency is decreased in roots of cotton plant due to shortage of oxygen supply which leads to loss of aerobic respiration. Under waterlogging stress active transport of minerals reduced, which supply nutrients to other organs of plant (Ashraf et al., 2011).

v. Loss of Yield

Yield losses occur due to increased duration of waterlogging stress. Lint yield is reduced to 18.3% by waterlogging of 4 to 32 hours (Hodgson, 1982). Zhang et al. 2016 proposed that yield is greatly affected by waterlogging a early stages of plant growth and development

then late ones. The stage of growth and development or age of the cotton plant also shows effect on yield due to waterlogging. Rate of shedding is increased due to decrease in number of bolls (Bange et al., 2004).

In some studies (Zhang et al., 2008), (Bange et al., 2004), (Wang & Shen, 2001), (Hodgson, 1982) stated that yield loss due to waterlogging is because of decrease in number of bolls rather than weight of boll loss or reduction in percentage of lint.

3. Adaptability of Cotton to Waterlogging

Under waterlogging stress plant quickly adapt many physiological, morphological and molecular strategies to reduce the yield losses. Cotton adapts three primary mechanisms i.e.: strategy of escape, adaption of quiescence or mechanism of self regulation and compensation to waterlogging stress.

i. Strategy of Escape

Escape strategy includes the formation of adventitious roots, formation of aerenchyma and elongation of stem. Formation of adventitious roots is related to ethylene signal production. Ethylene responsive factors (ERFs) which depend on available oxygen plays important role in tolerance of cotton plant against waterlogging (Zhang et al., 2015). To permit aerobic respiration aerenchyma is formed which provide the low resistance pathway for oxygen movement in these gas filled channels. Elongation rates of stem, leaves and petiole accelerated in some species when plant is under complete submergence (Colmer et al., 2014). Elongations of different parts of plant allow it to remain above the surface of water all the time under waterlogging. Hattori et al. 2009 proposed that there are two genes SNORKEL I (SK1) and SNORKEL II (SK2) triggers the elongation of different parts of plant under water logging and gibberalic acid GA participates in it as well.

ii. Strategy of Quiescent Adaption

Quiescent adaption strategy includes the change in activity of protective enzymes, alteration in hormone concentration and distribution, difference in expression of genes or signaling of NO and H2O2 in cotton.

Under waterlogging, quiescent strategy retards the plant growth and development by changing in various metabolic reactions and lowers the consumption of energy. Usually antioxidant activity of enzyme is increases under waterlogging stress which leads to reduce damage (Zhang & Dong, 2015), (Dong et al., 2003). Waterlogging alter the distribution mechanism of different hormones with increase in synthesis of absissic acid (ABA) by lowering the formation of ctyokinins (CTK), indole acidic acid (IAA) and gibberalic acid (GA) in leaves of plant. ABA content in cotton plant increases by inhibition of GA, ZR and IAA (Guo et al., 2010). GA act as important component of maintaince in growth because it act as growth hormone while IAA act as regulator of growth and development (Morris, 1993).

Zhang et al., 2017 proposed that salicylic acid (SA), jasmonic acid (JA) and barassinosteriod (BR) are growth regulators which involved in waterlogging response in plants. Energy metabolism pathway converted the anaerobic fermentation process from oxidative phosphorylation to maintain the level of ATP by suppressing the storage metabolism (Bailey-Serres et al., 2012), (Bologa et al., 2003), (Geigenberger et al., 2000).

iii. Strategy of Self Regulation and Compensation Mechanism

Indeterminate growth habit of plant helps in self regulation and compensation ability of cotton plant under waterlogging stress. New organ is formed when old one is damaged by recovery mechanism and regeneration ability. For instance, when apical buds of cotton plant damaged than axillary buds activated for formation of new root cells. In order to compensate the yield losses due to waterlogging stress plant growth and development is accelerated.

4. Measures for waterlogging mitigation

Many measures including adaption of tolerant varieties by advance breeding methods, soil fertilization and foliar, application of plant growth hormones which act as regulators for growth and development of plants and

agronomic measures can also use for management of waterlogging stress.

SUMMARY

Under waterlogging stress severe yield losses occur in production of cotton worldwide. The supply of oxygen reduced which alter many plant mechanisms and retard plant growth and development. Many adaption strategies developed by cotton plant due to its indeterminate growth habit which maintain the balance between different mechanisms of plant under stress. But all these measures are limited and it is need of time to develop waterlogging tolerance on molecular and biochemical basis. Many novel genes are expressed for waterlogging tolerance in CDNA libraries of roots and shoots of stressed plants.

It is concluded that waterlogging tolerance is improved by many strategies like: applying proper dosage of fertilizers, development of resistant varieties, updating of agronomic measures and use of the new molecular techniques instead of conventional plant breeding methods.

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