MedCrave Online Journal of Biology and Medicine

Review article

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Approaches for sustainable production of soybean under current climate change condition

Abstract

Soybean is an important cash crop, cultivated worldwide for food, oil and feed production. Soybean production worldwide in 2020 was 353.5 million metric tons. This plant however, faces many challenges due to climate change. Increase in temperature, drought, floods etc. are the outcomes of climate change. These have a clear negative impact on soybean cultivation. This ultimately leads to food insecurity and economic losses. This review focuses on approaches which can be employed to address the climate change associated challenges in sustainable soybean production. The approaches like genetic engineering, aeroponics, nanotechnology, development of cultivars, plant pigments and hormones usage can be opted to help combat the impact of changing climate. Management of soybean under adverse climate change conditions will increase the yield and bring agriculture based economic prosperity.

Keywords: aeroponics, climate change, drought resistance, heat resistance, soybean, yield

Volume 8 Issue 1 - 2023

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Received: January 13, 2023 | **Published:** March 03, 2023

Introduction

Soybean (*Glycine max* (L.) Merrill) is among the top 10 most cultivated crop species worldwide. This has huge significance as food and feed.[1] In 2020, 353.5 million metric tons of soybean was produced worldwide. The cultivation estimated area was about 127 million hectares. The leading soybean cultivating countries are Brazil, USA, Argentina, China, India, Paraguay, Canada, Russia, Ukraine and Bolivia. In year 2020/ 2021, soybean produced 70.86% plant derived protein food and 28.88% of plant derived oil.[2] Soybean is a significant crop used worldwide. This however, faces many challenges due to the changing climate. A major contributor of low soybean yield is drought.[3] About 40% soybean yield is lost per year due to water deficiency.[1] The rise in temperature is also wreaking havoc on agriculture. The soybean yield declines due to high temperature as well.[3] This leads to food shortage and economic losses. The aim of this review is to highlight the solutions to address negative impact of climate change on economically important soybean crop.

Approaches

Drought resistance induction

Drought is a drastic abiotic stress impacting plant growth. It was reported that if soybean plant seedlings are first treated with shade and then moved to light, their drought tolerance increases. Shade upregulated genes *NCED3* (Nine-cis-epoxycarotenoid dioxygenase 3) and *AAO3* (Abscisic aldehyde oxidase 3) involved in abscisic acid synthesis. This suggests that soybean seedlings should be pre-treated with shade to induce drought resistance.[4]

Melatonin regulates many physiological processes in plant growth. It is an indolamine bioactive molecule. It increases tolerance to abiotic stress in plants. When soybean seedlings were treated with exogenous melatonin (50 and 100 μM) (on leaves/ roots), drought stress tolerance was increased. The impact was more significant in rhizosphere than the leaves. Oxidative stress was reduced by lowering ROS (reactive oxygen species) and malondialdehyde. There was increased chlorophyll content and increased photosynthesis. Furthermore, melatonin application stimulated activity of antioxidant enzymes like peroxidase, superoxide dismutase, catalase, polyphenol oxidase and ascorbate oxidase. Drought causes an increase in proline and sugar content. This was counteracted by melatonin.[5]

The drought stress tolerance can be induced using beneficial microorganisms as well. When crops are inoculated with nitrogen fixing bacteria and plant growth promoting bacteria, the plant is imparted drought tolerance in arid/ semiarid environments. A study reported induction of drought tolerance to soybean when it was co-inoculated with *Bradyrhizobium japonicum* USDA110 (nitrogen fixer), and *Pseudomonas putida* NUU8 (plant growth promoting bacteria). This enhanced not just the drought tolerance, but also increased plant growth and nutrient uptake from soil. Hence, these strains can be used as biofertilizers in arid/ semiarid soybean fields.[6] Astounding soybean production in Brazil is by using same strategy by inoculation of soybean with different strains of genus *Bradyrhizobium*. This tends to major nitrogen needs of soybean plant, 60% of which goes to grains.[7] Genetic engineering to produce transgenic soybean plants is a good way to induce drought tolerance. *Panax ginseng* gene *PgTIP1* (Temperature shock-inducible protein 1) when introduced in soybean plant, induces drought and salt tolerance. This is done by maintenance of homeostasis of water, ROS and salts.[8] Another study reported drought tolerance in transgenic soybean (*AtNCED3* (9-cis-epoxycarotenoid dioxygenase) gene was introduced). *AtNCED3* gene codes for enzyme involved in biosynthesis of abscisic acid. The No. of pods, seeds and overall yield was increased.[9] Other drought tolerance genes used to produce transgenic soybean are shown in Table 1.

Protection against flooding/ waterlogging

Climate change has caused an increase in drastic climate related events. One of these events is increase in precipitation events in different areas of the world. This leads to more extreme floods and waterlogging.[17] Waterlogging can be defined as too much water in plant roots which leads to oxygen deficiency in rhizosphere. Waterlogging can also be due to extremely high rainfall, lateral flowing ground water, elevating water tables, poor drainage, poor irrigation or combination of these factors.[18] The impact of waterlogging are shown in Fig 1. Waterlogging is one of the key factors affecting soybean yield around the globe. In various regions of the world (like Asia and North America) where rice in paddy fields is rotated with soybean, flooding decreases the yield of soybean by 25%. Flooding reduces

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soybean yield from 17-43% in vegetative state,[19] and 50-56% during reproductive state.[20] Several soybean breeders have hence, developed various varieties of soybean tolerant to flooding. The waterlogged tolerant genotypes include PELBR11-6042, PELBR10-6000, and PELBR11-6028, while cultivars include TEC IRGA 6070 and BMX Potência.[21] An efficient way to improve economic problems associated with low yield due to water logging, is inducing tolerance to it. This can be done by genetic engineering.[22] Soybean plant introduced with *Adh2* (alcohol dehydrogenase) showed improved seed germination under flooding conditions. Adh protein is increased in root tips, where high energy supply is needed for active cell division. Transgenic soybean showed reduction in flooding stress. It is speculated that *Adh2* gene might have altered glycolysis and alcoholic fermentation leading to better seed germination of soybean under flooding conditions.[23]

Table 1 The drought tolerance induction in soybean via genetic engineering

S. no.	Gene	Mechanism	References
1.	GmWRKY54 (WRKY DNA Binding Protein 54)	This gene codes for transcription factor that cause expression of stress related genes like PYL8, CPK3, CIPK11 and SRK2A. This activates Ca2+ signalling and abscisic acid pathways.	Wei W et al.[10]
2.	GmNFYA5 (Nuclear Transcription Factor Y Subunit Alpha)	The gene imparted drought tolerance by activating abscisic acid dependent and independent genes involved in stress tolerance.	Ma XJ et al.[11]
3.	DREB2 (Dehydration-Responsive Element-Binding Proteins 2)	The gene imparts drought tolerance by activating stress related genes.	Marinho JP et al.[12]
4.	GmNAC8	NAC proteins belong to TF families and regulate genes involved in plant development and abiotic stress. By upregulation of stress related genes, drought tolerance is conferred.	Yang C et al.[13]
5.	GmNFYB17 (Nuclear Factor Y-B Transcription Factor)	A TF that causes upregulation of drought tolerance genes	Sun M et al.[14]
6.	AtAREB1 (Abscisic Acid Responsive Element Binding Protein)	Regulate genes which protect against dehydration	Caranhato et al.[15]
7.	GmSAP5 (Stress Associated Protein 5)	Imparts the drought tolerance by reducing stomatal aperture	Hou Z et al.[16]

A study reported that treating plants with ethephon shows great promise. Ethephon is source of ethylene, a phytohormone. Application of ethephon alleviated waterlogging stress and improved pigments of photosynthesis. The treatment increased amino acid content. It initiated adventitious root initiation, enhanced surface area of roots, and increased glutathione transferase expression. The protein content of these plants was also higher than those not treated with ethephon. Furthermore, there was decrease in ROS, cell damage mitigation and enhanced phenotype.[24] Genetic engineering can also be used to induce tolerance against flood in soybean plant. Specific proteins are produced in different plants to cope with flooding/ waterlogged conditions. These can be introduced into the soybean plants to induce tolerance. XTHs (Xyloglucan endotransglycosylases/ hydrolases) are enzyme class that play role in constructing and remodelling of crosslinks formed by cellulose/ xyloglucan. The remodelling allows regulation of cell wall extensibility. The *AtXTH31* gene was isolated from *Arabidopsis* and used to produce transgenic soybean. The transgenic soybean displayed better tolerance to flooding stress. There was greater germination rate, increased root length during seedling stage and vegetative stage (Figure 1).[25]

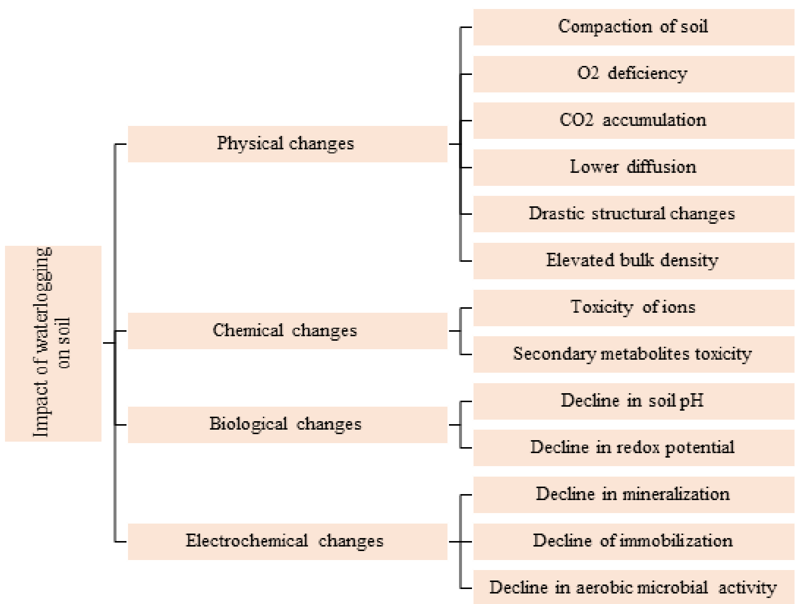

Figure 1 Impact of waterlogging on soil. This leads to low crop yield and economic losses.

Citation: Fatima A, Jan SA. Approaches for sustainable production of soybean under current climate change condition. *MOJ Biol Med.* 2023;8(1):27–31. DOI: 10.15406/mojbm.2023.08.00179

Aeroponics

Aeroponics is a great approach for crop production. The process is carried out in completely controlled conditions. Plants are placed in growth chamber/ area, and mist of nutrient solution is provided. This process does not use soil, but the nutrient mist does cater all the nutritional plant requirements. This is ejected via atomizing nozzles, periodically. Temperature, light, humidity, pH, carbon dioxide concentration and nutrients are all carefully monitored and controlled. This can be used for soybean cultivation as well in areas where land cultivation is not a possibility.[26] Different advantages of aeroponics are shown in Figure 2. Aeroponics in light of harsh climates, provides a very good solution in production of soybean (Figure 2).

Figure 2 Advantages of aeroponics for sustainable Soybean production.

Temperature resistance induction

According to estimations, temperature will increase by 1.5°C in coming 2 decades. This affects agronomic traits like biomass production, yield, physiology, phenology etc. Oil seed crops like soybean are suffering at hands of increasing temperature. The oil content and number of seeds decline with rising temperature. This in turn has drastic impact on food security and economy. The seed and oil loss is due to the fact that natural plant defence can't stand the heat stress.[27] Temperature tolerance can be induced by a variety of ways. One of them being use of beneficial microbes. Using endophytic bacteria which can promote plant growth provide an eco-friendly solution for agriculture improvement. These bacteria also have potential to counteract the adverse impact of heat stress. *Bacillus Cereus* SA1 is an endophytic bacterium which produces biologically active metabolites like indole-3-acetic acid, gibberellin and organic acids. When this was inoculated in plants, an improvement in biomass and chlorophyll content was noted. Furthermore, the tolerance was induced in soybean plants for 5-10 days. Inoculation increased antioxidants like glutathione, ascorbic acid peroxidase and superoxide dismutase. A decrease in abscisic acid and increase in salicylic acid was also noted. SA1 inoculation caused the expression of *HSP* (Heat shock protein) proteins. There was also overexpression of stress related genes *GmLAX3* (Auxin influx carrier) and *GmAKT2*. These may have involvement in reduction of ROS and elevated potassium gradient (critical for plants in heat stress).[28]

Genetic engineering can also induce temperature tolerance in soybean plants. A protein *GmEF8* (Elongation factor) was introduced in soybean plants. This interacts with *GmCBL1* (Calcineurin B-like protein 1). *GmEF8* are expressed under abiotic stresses like heat and drought. The overexpression of *GmEF8* caused heat and stress tolerance in transgenic soybean and overall had high protein content. Hence, *GmEF8* also has great potential in inducing abiotic stress tolerance (heat and drought) in soybean.[3] Use of phytohormones and pigments is also being investigated to address the abiotic stresses associated with climate change. The application of melatonin on leaves of soybean plant increase heat stress tolerance in it. Harsh environment cause increase in melatonin as a defence mechanism.[29] Heat stress harms plants by producing ROS, leading to disturbance of plant growth and development. Applying melatonin addresses this issue and increases photosynthetic pigment. There was increase in heat shock proteins and transcription factors which cause ROS detoxification.[30] Melatonin also promotes production of isoflavones and promotes cell division under heat stress.[31]

Statistical modelling

Agriculture based economy is adversely affected with climate change impact. Statistical analysis can predict about different situations to help us adapt to it. Such a statistical evaluation predicted which genotypes of soybean are best under drought and saline conditions. Since, both these are limiting factors which prevent soybean establishment, first multi environment trials were conducted on 46 cultivars of soybean. Then the data was analysed to see impact on germination of seed and initial growth. After evaluation, it was suggested that best performing soybean genotypes under drought and saline environment are FPS Solar IPRO, NS 7300 IPRO, FPS Antares RR, TMG 716 RR and AS 3610 IPRO.[32] These specific genotypes can be used in drought impacted lands. Furthermore, similar strategies can be opted for production of soybean.

Nanotechnology

Nanotechnology research focus on agricultural sector has provided quite promising results. Metal based nanoparticles (NPs) are being tested on plants as an alternate to nutrients and stimulants. The plant response to drought increases with NPs application. It was reported that using zinc oxide, cobalt, iron and copper nanoparticles on soybean under drought conditions was analysed. It was noted that these NPs induced drought tolerance in soybean. There was significant impact on biomass reduction, drought tolerance index and relative water content. The NPs caused expression of drought resistance genes like *GmERD1* (Early responsive to dehydration 1) in soybean.[33] Another study conducted, applied carbon dots (CDs) on soybean leaves under drought stress. It was noted that CDs scavenged ROS (produced under drought). The outcome was increased photosynthesis and transportation of carbohydrate. CDs promoted root secretions like auxins, amino acids and organic acids. These recruited beneficial rhizosphere microbes like *Glomeromycota, Actinobacteria, Acidobacteria* and *Ascomycota*. They facilitated the nitrogen activation in soil. There was upregulation of genes *GmNRT* (Nitrate transporter), *GmAQP* (Aquaporins), and *GmAMT* (Ammonium transporter) involved in enhanced uptake of nitrogen and water. There was enhanced amino acid biosynthesis and nitrogen metabolism. The soybean yield increased by 21.5%. The protein and amino acid content of soybean also increased with foliar application of CDs.[34] Therefore, using nanotechnology to produce soybean is an attractive option under current climate change. Soybean plants'

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roots when exposed to aluminium oxide (Al_2O_3) NPs, showed better tolerance to flooding stress than the non-treated soybean. Al_2O_3 NPs treatment enhance soybean growth. In plants treated with Al_2O_3 NPs, there was decrease in energy metabolism as a consequence of changes in protein profile. Furthermore, it was noted that these plants showed decrease in cell death. Hence, to address flooding stress in soybean, one can simply use Al_2O_3 NPs for regulation of growth, cell death and energy metabolism.[35] Since, plant growth and yield are our major concern in changing climate, nanotechnology can be used for that as well. Magnetite NPs coated with citric acid, when used on soybean, increased chlorophyll content, growth of plant and root surface. There was no evidence of cell death or oxidative damage. These are hence, a good option to increase plant productivity.[36]

Conclusion

Sustainable production of soybean is an absolute necessity of mankind. This is used as food, oil source and livestock feed. Soybean is produced all around the world. However, due to changing climate, a lot of challenges are emerging for soybean growth and development. These include temperature increase, drought, flood etc. As a result, the yield of soybean is affected. The solution to these challenges lies with use of nanotechnology, genetic engineering, aeroponics etc. These will help protect soybean from adverse climate impact. The outcome will be prevention of low yield due to adverse climate. Higher soybean production sustainably will also be beneficial for the economy.

Acknowledgments

None.

Conflicts of interest

The authors declare that there are no conflicts of interest.

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DOI: 10.15406/mojbm.2023.08.00179