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CLIMATE CHANGE A MAJOR THREAT TO AGRICULTURE: A BRIEF REVIEW

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ABSTRACT
Climate change for agriculture is a great threatening adversity in under developed countries due to their more dependence on agriculture and increase in greenhouse gases. Agricultural practices are influenced by climate change because they rely mainly on climatic factors. This review covers the factors affecting the climate change and explains strategies for the development of adaptation in plants against climate change. Climate affects the agricultural soil by directly by changes in organic carbon transformations and indirectly by cumulative impacts of CO_2 along with fertilizer application practices and variable efficiency of Radiation use. Many gases are produced due to burning of fossil fuels; they include methane and oxides of Carbon, sulphur and Nitrogen. Climate change also increases the drought and heat stress for agriculture. These gases mainly come from the use of fertilizer on the agricultural soils, livestock manure, tillage practices, and fossil fuels. Now different strategies *i.e*. Agroforestry, omics, Genome wide association studies and CRISPR/Cas9 are used for screening the plants against climatic change.

KEY WORDS: Climate, Agriculture, Soil, Biotic and Abiotic Factors, Strategies.

1. INTRODUCTION

Climate change is a major worldwide environmental problem and effects all types of life. It defines as change in climate with the passage of time due to the natural changes (Natural fluctuations in the sun's intensity, Volcanic eruption, Shorter- term cycles like El-Nino) or due to human movement (excessive use of fertilizers, tillage, fossil fuels *etc*.) or define as significant variation by statistically in state mean of the climate[1]. Greenhouse gases increase that is the reason to increase biotic stresses (diseases, insect attack) and abiotic stresses *i.e.* drought, temperature, heat [1][2].

Climate changes badly influences the agricultural land, crops, forest ecosystems and disturb different agricultural magnitudes, causing yield losses, effectiveness and occupation. Food security is another major threat due to variation in climate[3], due to the unpredictable crop production, fluctuations in markets, prices of food and supply network[4]. The choice of the optimum crops cultivated, optimum planting time and harvesting time mainly base on the weather circumstances prevalent everywhere [5]. Soils are essential portions of numerous universal nutrient cycles. Climate change effect agricultural soil by (i) direct effects include alterations in organic matter and nutrient circulation linked with alter in moisture and temperature in the soil to hence soil erosion due to an increased and uneven rainfall[6] (ii) indirect effects of climate change are normally predicted to increase crop yield because of fertilization, carbon dioxide, radiation use efficiency and longer growing seasons [7].

Nitrogen and Carbon are vital constituents of organic matter of soil[8] and it can change into carbon dioxide (CO_2) cause greenhouse effect in atmosphere, 4% increase per year and increase rain fall variability, methane (CH_4), and nitrous oxide (N_2O), 4.5 million tons of (N_2O) produce per year[9][2]. Use of non-renewable energy reservoirs, tillage of soil and greenhouse gases has changed the equilibrium of nature[10]. Drought and heat are the most important factor of climate change which effect agriculture soil and crop productivity. Increase in temperature and decrease in the rainfall reduce the water supplies and difficult to meet the water demands.

Different strategies used to compete with the climate change. Forest development to decrease the influence of water deficit, prevent barren land formation and fix destroyed soil[11]. The new technologies omics are using to study the crop plants by genomics, proteomics and transcroptomics. It helps us in study the interaction of genes, proteins and metabolites [12]. Genome studies used to study the gene changes and linkage in the traits [13]. In biotechnology stress tolerant plants are developing by the use of genetic engineering for the human beings[14]. Now these day CRISPR/ Cas9 technique use for the development of biotic and a biotic stress tolerant plant [15]. Present study covers the identification of factors which enhance the climate change and strategies to decrease and compete with climate changes.

2. CLIMATE CHANGE AND AGRICULTURAL SOIL

2.1 What is climate change?

Climate change refers to alteration in climate with passage of time, because of natural changes or due to human action [16]. Worldwide, climate change is severe threat that badly affects agricultural yield and quality [17]. The accumulation

of toxic gases produced as a result of Greenhouse effect is the biggest cause of changes in environment. Climate change is strongly linked with agriculture, this association is as important as the difference between population and food productivity[18]. International contribution of different sectors in climate change shown in table 1.1.

TABLE 1.1: International contribution of different sectors in climate change

Sr. No.	Sectors	Percentage	References
1	Energy supply	25.9	[1]
2	Industries	19.4	
3	Forest Development	17.4	
4	Agriculture	13.5	
5	Transports	13.1	
6	Housing and Private building	7.9	
7	Wastage	2.8	

2.2 Soil and climate change

Soil is major component of the ecosystem and hence climate. It is considered the second great reservoir of Carbon first being the seas and oceans. Soils form the surface on which all terrestrial ecosystem functions [19].

Soil and Schemes related to it have immense importance as they are applied in manufacture of Biomass, Provide Habitats to Living things, maintaining the Biodiversity, in water cleansing, controlling the hazardous eruptions, Air purification Role in carbon uptake and provide the cultural, recreational and human health benefits [20]. Planting is directed to adverse changes in soil organic carbon by changing the mechanisms involved with soil Carbon production and decay [21][22]. Carbon content in the soil is altered by many processes which are dependent on many components such as pH of the Soil, Air temperature, Soil texture Agronomic practices such as Tillage Changing the cropping Pattern and Water upholding capacity of soil [8]. Change in soil properties is because of change in environment [23].

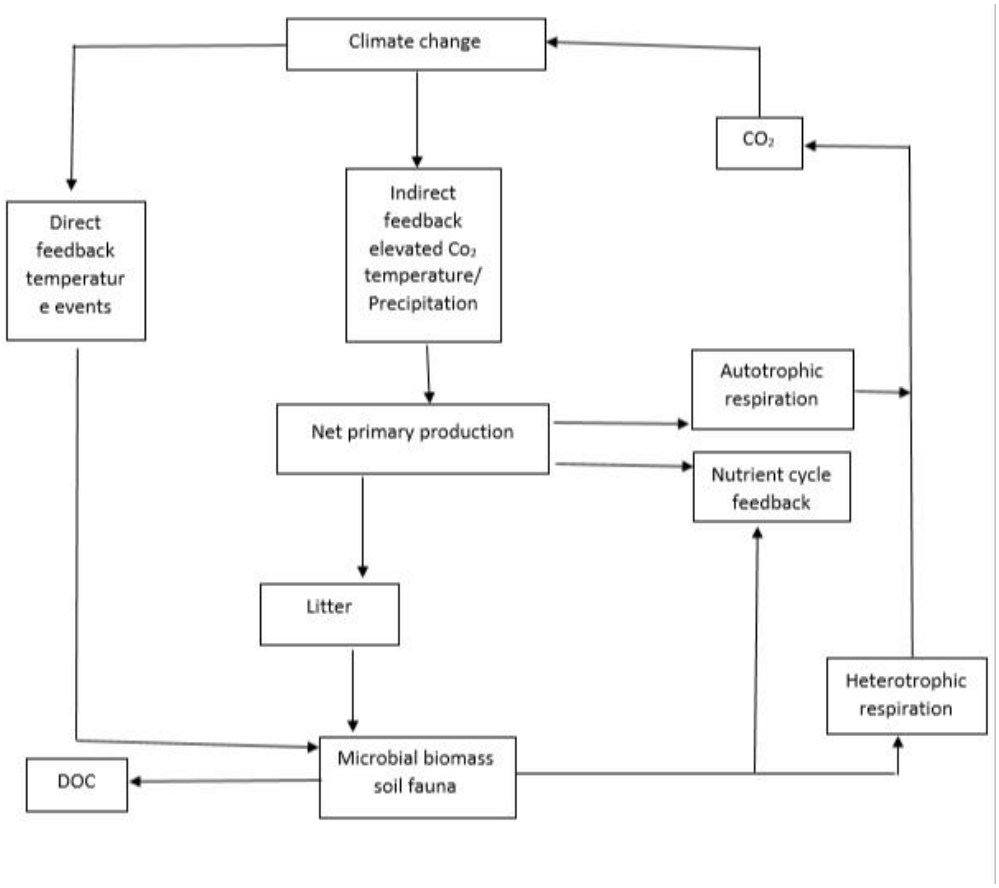

FIGURE: 1.1. Direct and indirect effects of climate change

2.3 Influence of climate change on soil

Increases in temperature, droughts, Downpours, storms, chilling injury and expanding sea surface levels in coastal areas are due to climate change. It increases the threat to soil like reduced soil fertility, soil compaction, soil erosion, and reduced crop yield [24]. These threats linked to climate increase big problems about the soils as nutrient media in future [25]. The soil is affected by the changes in

ecosystem gradually and slowly because this is not directly associated with climatic changes. There are some components that are directly (temperature) and some indirectly (fluctuations in soil humidity) this can resultantly act as source of many greenhouse gases [26].

a. Direct effects

Alterations in processes related to soil like carbon transformation circulation of the nutrients and relative changes in moisture due to heavy precipitation causing soil erosion are perceived as direct effects[27]. Proper management of soil and climate adversities can alter the capability of the soil to perform in different situations. Different studies have reported the impacts of climate change to different soil functions[28] [29]. Organic soils of UK showed a reduced Capacity to retain the C in increased soil temperature and reduced soil moisture [28].

b. Indirect effects

In some Crops like those using C_3 pathway for photosynthesis climate change can cause enhanced yield as it alters the parameters like fertilization, radiation use efficiency and prolonged growing season[7] but plants having C_4 pathway do not show this [30]. Increase in CO_2 can cause enhancement of dry weight and other plant parameters. Indirect impacts can also be due to on soil practices, these also include the practices done for the adaptations to environmental variations [31].

Many agricultural practices related to soil adaptation including reforms in agricultural irrigation systems, changing cropping schemes and patterns and changing the fertilization quantities and practices. These include soil improvement practices shown in fig 1.1[32].

Climate change also imparts effects on different soil morphological factors *e.g.* soil morphological parameters (soil structure, soil texture, soil water contents), soil biological parameters (organic matter of soil, fauna and flora in the soil) and soil chemical parameters [33].

3. Climate change and agriculture

The impacts of climate change are linked directly with agriculture. Agriculture is the fundamental area that is greatly affected by climate adversities[34]. Selection of appropriate crops and their sowing and harvesting times are based on climatic features of a specific area. It is clear that the changes in climate are controlling the farmer's income as production and quality are under control of climatic variation[5]. The speed of climate change is very high as it can be observed through the fact that the temperature of modern day has been increased 5.0°C higher than last era of ice age [35]. So, in order to cope with this dramatically increasing scenario there is a dire need of quick actions to alleviate the adversities of climate change. From previous decade agricultural production and quality are immensely deteriorated due to climate change for instance due to temperature as well as precipitation fluctuations[36]. There is uncertainty about the severity of droughts and floods and winds and sudden damage is expected to be lethal. It could also the cause of permanent water deficits, Deserts formation, Soil erosion and many other devastating factors such as diseases or variation in atmospheric pressure of air and water level. Susceptible regions face severe crop losses in case of such changes[37]. Climate change can have positive effects in some area [34]. As a result, there is direct impact of climate change on food productivity of the world [38].

Agriculture is the primary area that is immensely damaged by the climate change and hence the farmer community that is damaging for the economics and a great reason of rural poverty. And this impact is going to be very intense in under developed or progressing countries that are entirely relying on their agriculture for economic growth [39]. For example, 70% of population of Pakistan is related to agriculture one way or the other and the livelihood of these people is dependent on agricultural production. Similarly, agriculture plays 70% role in GDP (gross domestic product) of Pakistan's economy.

3.1 Effects on CO_2:

Due to increasing consumption of Fuel and Burning activities the CO_2 level in Atmosphere has gone to higher concentrations. Human activities have intervened the climate and now CO_2 is causing greenhouse effect in the atmosphere. Two issues are of main concern to economists first is the speed or pace at which CO_2 is accumulating and total amount of CO_2 accumulated. From the last century the amount of CO_2 dumped in atmosphere in the form of emissions has increased to 4% and level of CO_2 in atmosphere is increasing at a rate of 1-2% per annum. If this rate remains, the same then after 50 years' amount of CO_2 will double up. The use of fossil fuels in developed countries will be replaced by some other alternatives due to increasing prices and income [40].

CO_2 is involved in the absorption of upto20% of thermal radiations [41]. It is produced naturally as a result of degradation of organic matter, breathing activity of living things and Oceanic release. Man has created many sources which directly or indirectly responsible for CO_2 emissions they include cement factories, forest destruction, burning tons of fossil fuels in form of petrol, gas and coal. According to estimation 24% of CO_2 is emitted by agro-forestry and other land practices and 21% by industry [42]. The atmospheric carbon dioxide has reached to a level of 385 µmol. mol−1 in 2018 from 275 µmol. mol−1 in 1750. It is estimated that due to increased CO_2 concentration due to human activities will increase the temperature of earth by 3–5^{o}C in year 2100 [42].

3.2 Effects on Nox

No doubt Nitrogen is of prime importance and limiting factor for the plant growth and agriculture. Sometimes the soil could not provide the sufficient nitrogen to the plant grown in high intensity cultivated systems so it is required to provide the nitrogen from external sources for enhanced production. The use of fertilizers is immensely increased from 12 Tg (teragram) in 1960 to 113 Tg in 2010 shown in figure 1.2 [43].

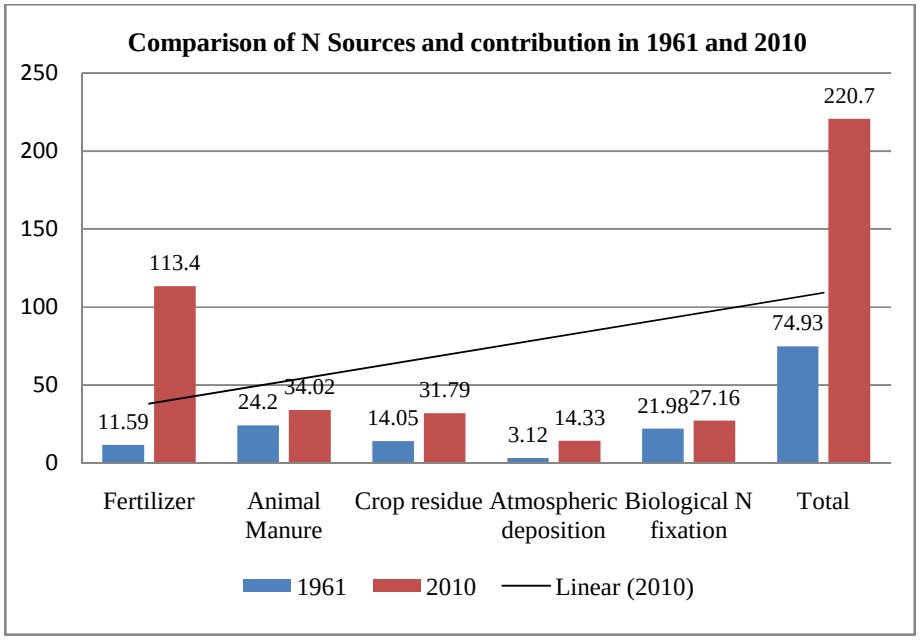

FIGURE 1.2: Comparison of N Sources and contribution in 1961 and 2010 [44]

If the trend continues then for feeding more population in the future more nitrogen fertilizer will be used in 2050[45]. The nitrogenous emissions along with other greenhouse gases are likely to drastically reduce the production of the crops and are threat to food security[46]. Emissions of Nitrogen pose very dangerous effects on agricultural systems *e.g.* N_2O has a very long life in atmosphere about 116 years and very high global warming potential (GWP) that is 310 times more than that of carbon dioxide and high global change temperature potential (GTP) on one hundred years-based calculations[47]. Nitrogen from Agricultural practices influence the climate by producing NH_3 and other oxides of nitrogen [48]. The NOx affect climate in different ways *e.g.* O_3 formation that is involved in warming, elimination of CH_4 by hydroxal radical and cause cooling.

3.3 Reactive Nitrogen Nr

A human activity also has raised the level of reactive nitrogen in the atmosphere and this includes various forms NH_4, NOx, Nitrate and Nitrites. These compounds are inter converted and are very much lethal to the plants and environment at cosmopolitan level[49][50]. NOx are producing some climate forcing agents such as ozone and aerosols and at the same time are reducing long termed climate forcing agents like methane. NH_3 causes aerosol enhancement in environment and N applied to soil changes Carbon exchange that vary proportion of Greenhouse gases among air and land [51]. The overall effect of Nr is reduced by CO_2 quantities, Nr amount and number of Nr species in environment. Some research reports show the collective impact of Nr at different levels as national and international [52]. There is a lack of planned study on climate [48]. China is the biggest source of Nr from industrial and Land activities [53], and its emissions are posing climatic effects are not only regional but global.

4. Impacts of climate-nitrogen interactions on Agriculture

Climate has close relationship with Nitrogen cycle. O_3 produced as a result of N interactions affect agricultural productivity. This will lead to more emissions of Nr from cattle and cropping patterns. The impacts of N include heat and higher precipitation and heat and they impede the fulfillment of nitrogenous demands of crop even after fertilizer application and more application will lead to increased N release to environment.

1. Higher temperature will lead to more release of O_3 and higher O_3 will cause reduction in yield and production of crops [54][55][56]. Model experimentation of O_3 under different concentrations showed greater effects on grain crops [57].
2. Temperature fluctuations will promote more NH_3 emissions[58], poor Nitrogen use efficiency causes more release of Nr to atmosphere and causes reduced production and higher death rate [59]. For compensating this reduction more N is applied and hence more N will be released in environment.
3. Recently heat stress is involved in the economic decline of $1.7 to $2.4 billion in Livestock sector of US [60].
4. More nitrogen emissions are observed when heavy precipitation or flooding as more nitrogen is flushed from washing off agricultural soils and can give serious impacts to underground water [61].
5. Microbial activity enhances in N rich soils associated with increased NO_2 level in atmosphere by agriculture fertilization practices. Process of NOx impacting the environment shown in figure 1.3.

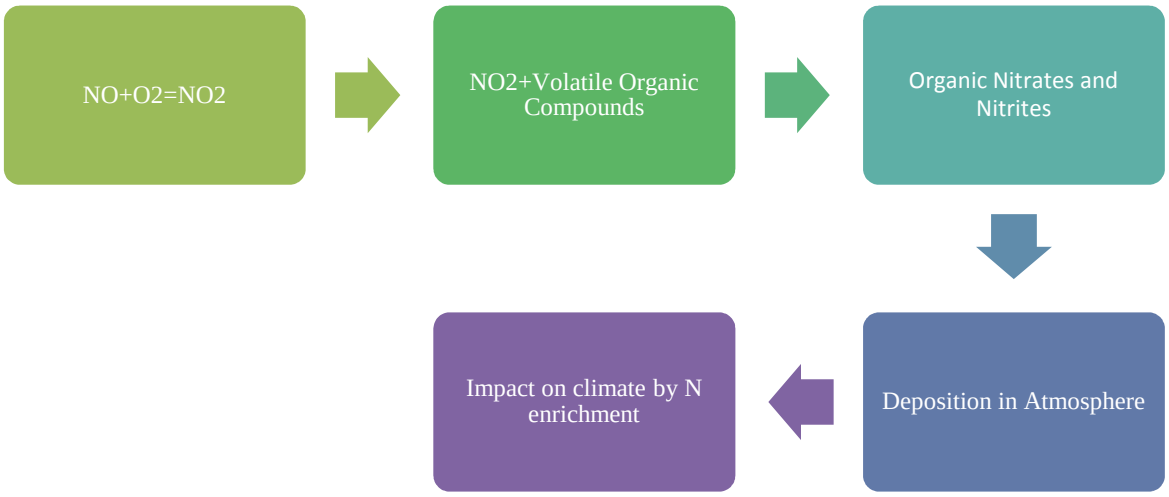

FIGURE: 1.3. Process of NOx impacting the environment

5. Impact of climate change on Drought and Heat

Drought is natural phenomena and climate change aggravates the conditions by increasing the rate of hydrological cycles and set them in faster and intensified and promoting the risks of wildfire. The hydrological cycle is speeded up because availability of energy for evapotranspiration is enhanced. The second reason is the increased temperature changes the water holding capacity of the atmosphere [62]. As a result, intensified, diverse and long lasting phenomena like droughts are observed. Hence it is obvious that temperature increase leads towards drought. High temperature has a crucial role in promoting drought due to global warming. Observations have shown that earth's temperature is gradually climbing up from previous century and by the termination of twenty first century (2080-2100) and it is predicted to be raised the limits of 1.5 to 2°C that is greater than the previous duration (1850-1900) [63][9][64]. This as a result increases precipitation and atmospheric moisture is increased many folds and this moisture holding capacity cause an increase of 7% rise per degree increase in temperature. This moisture level controls the amount of precipitation and hence there would be longer dry periods [65][30][66]. Under climate change the water content or division of soil moisture remains nearly constant at lower and higher altitudes. In such situations the amount of precipitation relies on available water content on both land and oceans [30][66].

The regions far from the seas are short of moisture to fulfil the evaporation requirement of atmosphere and this can lead to warmer temperatures, drying of islands and reduced humidity as in experimental models [67][68]. It takes more time for rehabilitation of moisture and it is crucial for precipitation and hence cause longer spells of drought [69]. The heat generated by global warming aggravates the conditions and causes quicker drying [70]. It results in wide spread, long lasting and intense spells of droughts as compared to recent climate [71][72]. It has been reported that in future the climate of land would be drier and areas under it will expand if the global warming will keep on increasing [73]. Weather patterns also determine the stability of a climate so, if once conditions promoted the drought then climate change aggravates the conditions by adding heat gradually to this system [74][62].

In addition to this humidity present in the soil is also related with increase in temperature. This is linked in a way that if there will be no moisture in the soil then there will be no evaporation and no cooling effect would be there and as a result the temperature will rise due to fluxes of heat [75][76]. This relationship of soil humidity and temperature is called temperature soil coupling [75][62] and this can cause the wild fire [77]. It is observed that humidity of the soil is inter linked with temperature extremes in local and international scale [78][79]. It is also reported there is a direct link between heat and dry circumstances and this can lead to drastic drought and heat stresses [80]. In future the drought and heat can have serious impact on climate and all this is due to climate change [81][82].

The role of temperature has discussed to high extent in context of drought. The temperature extremes result from climate change at bigger level and man interventions with Natural resources and disturbance in nature. Hot and cold temperature extremes both are lethal and cause severe and long lasting impacts. The mortality rate is linked with high temperatures in some areas but in temperate areas cold temperature is a trouble. Temperature fluctuations affect the food production in many areas sensitive to these changes including tropics and subtropics. In the countries where farm mechanization and technology in agriculture have reached to climax may get advantage of this if proper managements are done [83]. At high to mid latitudes production of some crops tend to enhance for small increase in temperature from 1-3°C. conversely at lower latitudes the minute increase in temperature can diminish the productivity of the crops and chances of hunger or famine may spread [84].

FIGURE: 1.4. Causes of global warming and methods to save earth

6. Genetic and genomic strategies to tackle outcomes of climatic variations

a. Omics-Led Breeding

The term "omics" is related to many eras of study like, genomics, proteomics and transcriptomic. Omics helps us to get a clear understanding of biological approaches that are complex and based on interactions of genes, metabolites and proteins in a genotype[12]. Omics approaches assists in description of biological processes related to genetic information for the amendment of crops [85].

Many objective-based markers are developed and studied. These markers scanned across different environments to get unique and contrasting variations and genes related to these functions are scanned for significant ecological traits [86].To recognize the phenotypes in different circumstances genetics and transcriptomic analysis can be utilized [87]. Genomics also help us with identification of molecular processes associated with stress resistance. This helps us to devise climate smart crops under changing climatic conditions [88].

b. Genome Wide Association Studies (GWAS) as a solution for Stress Resistance

To find out genetically different genotypes in different varieties, different allelic combinations are found with the help of genome wide association. This can also be performed for a single trait [89].

This technique has been proved to be quite useful in exploitation of mechanisms responsible for the tolerance to specific crop against climate [13].

Genome wide association is primarily based on Design, tools used for genotyping, statistical tools for elaboration of results. It shows the linkage between traits and SNP markers [90]. Plants have shown many successful resistances against climate using this technology due to broad applications against water deficit, salinity and heat stress [91][92][93]. Chen *et al*. 2017 screened Sorghum for changing climate. The traits like leaf firing, Blotch and heat tolerance at vegetative phase. Association between the resistance against climate and SNPs was determined using genome wide association [94].

c. Genetic Engineering and stress tolerance

Genetic engineering is one of the applied branches of Biotechnology that has played a significant role in the field of developing the plants against biotic and abiotic stresses and using them for human welfare. Different sort of data can be retrieved from the genomes and then changing these genomes through different techniques, genetic engineering acts as a strong tool to do that. In living organisms there are specified transcription factors which respond to special type of external stress. Transcription factors are particular proteins that can help in reduction the effect of stresses by reducing the signal streaming of a specific stress. Genetic engineering helps us to find these stress sensitive transcription factors in the genome. This strategy is reported to be successful in developing resistance in plants against stresses. These (Tfs) have the potential to vary the phenotypic expression of genes[14]. Different plants having resistance against different stresses have been developed through genetic engineering and they have shown a promising adaptation to climatic stresses[95][96][97]. Numerous transcription factors (TFs) are important as plant-specific TFs which includes AP2/ERFBP group[96]. This family of AP2/ERFBP TFs is concerned with different growth mechanisms and functions in influencing biotic and abiotic stresses [98].

d. Genome Editing Strategies

Genome editing (GE) is a tool used to change the plant genetics through sequence-specific nucleases. It is used for the improvement of crops to fulfill the food security and modified plant that can face the climate change[99]. Conventional plant breeding method used for the discovery of gene which linked with traits and GE used for

the best line for yield [100]. Plant genetics diversity decreases due to wide growth area of important crops which increase the susceptibility for abiotic and biotic stresses [101][102]. GE is commonly used for the transfer of gene in other plant genome to increase resistant for stresses as compare to conventional breeding due to time consuming [103]. GE plays important role in the modification of plant for resistance and high yield [104]. In GE, site specific endonucleases are utilizing i.e. zinc-finger nucleases, effector nucleases and CRISPR-Cas9 [105]. CRISPR/Cas9 is most commonly used for GE as compare to ZENs and TALENs due to the cheap, fast, precise and specific editing [106].

e. CRISPR/Cas9 System for Crop Advancement

An important system used for the improvement of crops for genetic resistance against abiotic stresses is CRISPR/Cas9 [15]. Immense potential is present in this system for developing climate resilient crops [106]. It is based on the utilization of internal defense mechanism of the prokaryotes. It is activated against RNA type 2 which is usually viral RNA hence these microorganisms tackle the attacking viruses [13][107][108]. The editing in the genome has been made easier and advanced with the help of CRISPR/Cas9. It produces gene mutants and silence the single nucleotides in whole system [109]. This tool is getting popular and widely accepted as at one side it is easy and eco-friendly and at the same time ensuring the genome edition and hence very useful in developing climate smart crops that can tolerate adversities of climate [110].

Shen *et al*. 2017 shared a success story about the silencing of Osann3 gene in Japonica rice by this system and as a result resistance against cold stress was developed [111]. In this way cold tolerance can be induced in transgenic rice due to potential of OsANN3 gene. Similarly, the resistance against herbicides is developed by a knocking down a special gene PmCDA1 using CRISPR/Cas9 [112].

7. Agroforestry: A Climate Smart Agriculture

Agroforestry is a planning system involving rational land-use that tries to find some balance in the growing of food crops and forests. Agroforestry have a well-known buffering and resilience effects on rapidly changing climate of ours. Agroforestry is the amalgamation of trees into farming systems. It has potential to reduce the effects of drought, to fix up degraded soil and prevent desertification. Agroforestry- A Climate Smart Agriculture, have buffering effect on changing climate because of permanent tree cover. Under the influence of changing climate, agroforestry besides acting as a buffer it can help to increase food production, provide different sources of nutrition, nutrient recycling and conservation, source of income and income diversification when crop yields are low [11]. Under the current scenario of global warming agroforestry plays a vital role in mitigation of climate change by absorbing greenhouse gases (GHG) through a carbon sequestration process [2]. With climate change expected to lead to unpredictable seasons in the future, placing even greater pressure on agricultural systems, food production and food prices, agroforestry is a viable option to help buffer farmers against the impacts [113].

8. CONCLUSION

It concluded that climate change directly links with agriculture and linkage more powerful in developing countries due to the more dependence on agriculture. Climate change is a major issue in developing counties because of inadequate adaptive ability and less modern technology. Industrial countries are the main sources of main gases of greenhouse agricultural and mechanical activities alter the climate by the eruption of these gases. Climate change also increases the drought and heat stress for agriculture. Developing countries should need to decrease the greenhouse gases by different ways to minimum the effect of climate. Different strategies like Agroforestry, omics, Genome wide association studies and CRISPR/Cas9 used for the study of climate smart breeding of plants and can use for the biotic and abiotic stresses.

REFERENCES

[1]. Wandre, S.S. and Shinde, V.B. Climate Change and Agriculture. Indian Farmer. 2015: 2(8):623-628.

[2]. Yohannes, H.A. Review on Relationship between Climate Change and Agriculture. J. Earth Sci. Clim. Change. 2016: 7: 335. doi: 10.4172/2157-7617. 1000335

[3]. Siwar, C,, Ahmed F, Begum RA. Climate change, agriculture and food security issues: Malaysian perspective. J. Food Agric. Environ. 2013;11(2):1118–1123

[4]. De Salvo M, Begalli D, Signorello G. Measuring the effect of climate change on agriculture: A literature review of analytical models. Journal of Development and Agricultural Economics. 2013 Dec 31;5(12):499-509.

[5]. Nastis S, Michailidis A and Chatzitheodoridis F. Climate change and agricultural productivity. Afr. J. Agric. Res. 2012: 7(35): 4885-4893.

[6]. Blum WE. Soil protection concept of the Council of Europe and integrated soil research. In Integrated soil and sediment research: A basis for proper protection 1993 (pp. 37-47). Springer, Dordrecht.

[7]. Paul EA. and Kimble J. Global climate change: Interactions with soil properties. ISBN. 2000; 13: 978-987.

[8]. Brady NC and Weil RR. The nature and properties of soils. Upper Saddle River: Pearson Edu. Pub. 4. 2008.

[9]. Hansen J, Sato M, Ruedy R, Lo K, Lea DW, Medina-Elizade M. Global temperature change. Proceedings of the National Academy of Sciences. 2006 Sep 26; 103(39):14288-93.

[10]. Brevik EC. Climate change, soils, and human health. In EGU General Assembly Conference Abstracts, 2013; 15.

[11]. Aid A. The time is now; Lesson from farmers to adapting to climate change. Retired from: www. actionaid. org. on August. 2008; 10:2009.

[12]. Van Emon JM. The omics revolution in agricultural research. Journal of agricultural and food chemistry. 2015 Nov 17; 64(1):36-44.

[13]. Mousavi- Derazmahalleh M, Bayer PE, Hane JK, Babu V., Nguyen H.T., Nelson MN, Erskine W, Varshney RK, Papa R and Edwards D. Adapting legume crops to climate change using genomic approaches. Plant Cell Environ. 2018. 42: 6–19.

[14]. Reynolds M, Tattaris M, Cossani CM, Ellis M, Yamaguchi-Shinozaki K, Saint Pierre C. Exploring genetic resources to increase adaptation of wheat to climate change. In Advances in wheat genetics: From genome to field 2015 (pp. 355-368). Springer, Tokyo.

[15]. Khurshid H, Jan SA, Shinwari ZK, Jamal M, Shah SH. An Era of CRISPR /Cas9 Mediated Plant Genome Editing. Curr. Issues Mol. Biol. 2017 Apr 15; 26:47-54.

[16]. Parvatha P. Climate Resilient Agriculture for Ensuring Food Security. springer, India, private; 2016.

[17]. Enete AA, Amusa TA. Challenges of agricultural adaptation to climate change in Nigeria: A synthesis from the literature. Field Actions Science Reports. The Journal of Field Actions. 2010 Feb 15;4.

[18]. Gornall J, Betts R, Burke E, Clark R, Camp J, Willett K, Wiltshire A. Implications of climate change for agricultural productivity in the early twenty-first century. Philosophical Transactions of the Royal Society B: Biological Sciences. 2010 Sep 27; 365(1554) :2973-89.

[19]. Montanarella L. Agricultural policy: Govern our soils. Nature News. 2015 Dec 3; 528(7580):32.

[20]. Tóth G, Gardi C, Bódis K, Ivits É, Aksoy E, Jones A, Jeffrey S, Petursdottir T, Montanarella L. Continental-scale assessment of provisioning soil functions in Europe. Ecological Processes. 2013 Dec; 2(1):32.

[21]. Lal R. Soil carbon sequestration impacts on global climate change and food security. Sci. 2004, 304: 1623–1627.

[22]. Wang G, Huang Y, Wang E, Yu Y, Zhang W. Modeling soil organic carbon change across Australian wheat growing areas, 1960–2010. PloS one. 2013 May 16; 8(5):e63324.

[23]. Hatfield JL. Climate change and the potential impact on the soil resource. Journal of the Iowa Academy of Science: JIAS. 1990; 97(3):82-3.

[24]. Lal R, Delgado JA, Groffman PM, Millar N, Dell C and Rotz A, Management to Mitigate and Adapt to Climate Change. J. of Soil and Water Conser. 2011. 66: 276–285.

[25]. Coyle C, Creamer RE, Schulte RP, O'Sullivan L, Jordan P. A functional land management conceptual framework under soil drainage and land use scenarios. Environmental Science & Policy. 2016 Feb 1; 56:39-48.

[26]. Diaz S, Grime JP, Harris J, McPherson E. Evidence of a feedback mechanism limiting plant response to elevated carbon dioxide. Nature. 1993 Aug 12; 364(6438):616-7.

[27]. Blum WE. Soil protection concept of the Council of Europe and integrated soil research. In Integrated soil and sediment research: A basis for proper protection 1993 (pp. 37-47). Springer, Dordrecht.

[28]. Ostle NJ, Levy PE, Evans CD, Smith P. UK land use and soil carbon sequestration. Land Use Policy. 2009 Dec 1; 26:S274-83.

[29]. Xiong X, Grunwald S, Myers DB, Ross CW, Harris WG, Comerford NB. Interaction effects of climate and land use/land cover change on soil organic carbon sequestration. Science of the Total Environment. 2014 Sep 15; 493:974-82.

[30]. Allen MR, Ingram WJ. Constraints on future changes in climate and the hydrologic cycle. Nature. 2002 Sep; 419(6903):228.

[31]. Haddaway, NRK, Hedlund LE, Jackson T, Kätterer, Lugato E, Thomsen I.K and Söderström B. 2015. What Are the Effects of Agricultural Management on Soil Organic Carbon in Boreo-Temperate Systems? Environ. Evi. 4: 23.

[32]. Mandryk M, Reidsma P, van Ittersum MK. Crop and farm level adaptation under future climate challenges: An exploratory study considering multiple objectives for Flevoland, the Netherlands. Agricultural systems. 2017 Mar 1; 152:154-64.

[33]. González E, Gálvez L, Royuela M, Aparicio-Tejo P, Arrese-Igor C. Insights into the regulation of nitrogen fixation in pea nodules: lessons from drought, abscisic acid and increased photoassimilate availability. Agron. 2001; 21: 607-613.

[34]. Mendelsohn RO, Dinar A. Climate change and agriculture: an economic analysis of global impacts, adaptation and distributional effects. Edward Elgar Publishing; 2009.

[35]. Duncan E.A Special Report On Climate Change And The Carbon Economy, The Economist, London, UK. 2009.

[36]. Kurukulasuriya P and Rosenthal S. 2003. Climate Change and Agriculture A Review of Impacts and Adaptations. The International Bank for Re-construction and Development/THE WORLD BANK 1818 H Street, N.W. Washington, D.C. 20433, U.S.A.

[37]. Rosenzweig C, Tubiello FN, Goldberg R, Mills E, Bloomfield J. Increased crop damage in the US from excess precipitation under climate change. Global Environmental Change. 2002 Oct 1; 12(3):197-202.

[38]. Bindi M and Olesen JE. "Agriculture." In M. L. Parry ed. Assessment of Potential Effects and Adaptations for Climate Change in Europe: The Europe ACACIA Project. Norwich, United Kingdom: Jackson Environment Institute, University of East Anglia. (2000).

[39]. Mohamed A. Ben N. Van D and Abdoussallam S. "Impact of Climate Change on Agricultural Production in the Sahel - Part 1. Methodological Approach and Case Study for Millet in Niger." Climate Change 2002. 54(3): 327-48.

[40]. Edmonds J, Reilly J. Global Energy and CO_2 to the Year 2050. The Energy Journal. 1983 Jul 1, 4(3):21-47.

[41]. Schmidt GA, Ruedy RA, Miller RL, Lacis AA. Attribution of the present- day total greenhouse effect. Journal of Geophysical Research: Atmospheres. 2010 Oct 27; 115 (D20).

[42]. IPCC (2014). Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panelon Climate Change, edsO. R. Edenhofer, Y. Pichs- Madruga, E. Sokona, S.

Farahani, K. Kadner, A. Seyboth, etal. Cambridge: Cambridge University Press.

[43]. FAOSTAT. Food and Agriculture Organization of the United Nations, Rome, Italy. (2016). Available at http://faostat.fao.org/

[44]. Fagodiya RK, Pathak H, Kumar A, Bhatia A, Jain N. Global temperature change potential of nitrogen use in agriculture: A 50-year assessment. Scientific reports. 2017 Mar 21; 7:44928.

[45]. United Nations, Department of Economic and Social Affairs, Population Division. World Population Prospectus: The 2015 Revision, Key Findings and Advance Tables. Working paper No. ESA/P/WP. 241 (2015).

[46]. Pathak H, Jain N, Bhatia A, Kumar A, Chatterjee D. Improved nitrogen management: a key to climate change adaptation and mitigation. Indian J Fertilisers. 2016 Nov; 12(11):151-62.

[47]. Shine KP, Fuglestvedt JS, Hailemariam K, Stuber N. Alternatives to the global warming potential for comparing climate impacts of emissions of greenhouse gases. Climatic Change. 2005 Feb 1; 68(3): 281-302.

[48]. Pinder, R.W., Davidson, E.A. Goodale CL, Greaver TL, Herrick JD, Liu L. Climate change impacts of US reactive nitrogen. Proceedings of the National Academy of Sciences. 2012 May 15;109 (20):7671-5.

[49]. Fowler D, Coyle M, Skiba U, Sutton MA, Cape JN, Reis S, Sheppard LJ, Jenkins A, Grizzetti B, Galloway JN, Vitousek P. The global nitrogen cycle in the twenty-first century. Philosophical Transactions of the Royal Society B: Biological Sciences. 2013 Jul 5; 368(1621):20130164.

[50]. Galloway JN, Townsend AR, Erisman JW, Bekunda M, Cai Z, Freney JR, Martinelli LA, Seitzinger SP, Sutton MA. Transformation of the nitrogen cycle: recent trends, questions, and potential solutions. Science. 2008 May 16; 320 (5878):889-92.

[51]. Erisman JW, Galloway J, Seitzinger S, Bleeker A, Butterbach-Bahl K. Reactive nitrogen in the environment and its effect on climate change. Current Opinion in Environmental Sustainability. 2011 Oct 1; 3(5):281-90.

[52]. Sutton MA, Howard CM, Erisman JW, Billen G, Bleeker A, Grennfelt P, Van Grinsven H, Grizzetti B, editors. The European nitrogen assessment: sources, effects and policy perspectives. Cambridge University Press; 2011 Apr 14.

[53]. Cui S, Shi Y, Groffman PM, Schlesinger WH, Zhu YG. Centennial-scale analysis of the creation and fate of reactive nitrogen in China (1910–2010). Proceedings of the National Academy of Sciences. 2013 Feb 5; 110(6):2052-7.

[54]. Mills G, Buse A, Gimeno B, Bermejo V, Holland M, Emberson L, Pleijel H. A synthesis of AOT40-based response functions and critical levels of ozone for agricultural and horticultural crops. Atmospheric Environment. 2007 Apr 1;41(12):2630-43.

[55]. Emberson LD, Büker P, Ashmore MR, Mills G, Jackson LS, Agrawal M, Atikuzzaman MD, Cinderby S, Engardt M, Jamir C, Kobayashi K. A comparison of North American and Asian exposure–response data for ozone effects on crop yields. Atmospheric Environment. 2009 Apr 1;43(12):1945-53.

[56]. Suddick EC, Whitney P, Townsend AR, Davidson EA. The role of nitrogen in climate change and the impacts of nitrogen–climate interactions in the United States: foreword to thematic issue. Biogeochemistry. 2013 Jul 1;114(1-3):1-0.

[57]. Avnery S, Mauzerall DL, Liu J, Horowitz LW. Global crop yield reductions due to surface ozone exposure: 2. Year 2030 potential crop production losses and economic damage under two scenarios of O3 pollution. Atmospheric Environment. 2011 Apr 1;45(13):2297-309.

[58]. Montes F, Rotz CA, Chaoui H. Process modeling of ammonia volatilization from ammonium solution and manure surfaces: A review with recommended models. Transactions of the ASABE. 2009;52(5):1707-20.

[59]. Nardone A, Ronchi B, Lacetera N, Ranieri MS, Bernabucci U. Effects of climate changes on animal production and sustainability of livestock systems. Livestock Science. 2010 May 1;130(1-3):57-69.

[60]. St-Pierre NR, Cobanov B, Schnitkey G. Economic losses from heat stress by US livestock industries. Journal of dairy science. 2003 Jun 1;86:E52-77.

[61]. Davidson EA, David MB, Galloway JN, Goodale CL, Haeuber R, Harrison JA, Howarth RW, Jaynes DB, Lowrance RR, Nolan BT, Peel JL. Excess nitrogen in the U.S. environment: trends, risks, and solutions. ESA Issues Ecol. 2012:15:1–16.

[62]. Trenberth KE. Changes in precipitation with climate change. Climate Research. 2011 Mar 31;47(1-2):123-38.

[63]. Moberg A, Sonechkin DM, Holmgren K, Datsenko NM, Karlén W. Highly variable Northern Hemisphere temperatures reconstructed from low- and high-resolution proxy data. Nature. 2005 Feb;433(7026):613.

[64]. Collins M. KnuttiR., Arblaster J., Dufresne J. L., Fichefet T., Friedlingstein P., Gao X., Gutowski WJ, Johns T., Krinner G., Shongwe M., Tebaldi C., Weaver AJ, Wehner M. 2013. Long-term climate change: projections, commitments and irreversibility. Clim Chang. 2013 Phys. Sci. Basis. Contrib. Work. Gr. I to Fifth Assess. Rep. Intergov. Panel Clim. Chang. 2013:1029–136.

[65]. Sun DZ, Held IM. A comparison of modeled and observed relationships between interannual variations of water vapor and temperature. Journal of Climate. 1996 Apr;9(4):665-75.

[66]. Trenberth KE, Dai A, Rasmussen RM, Parsons DB. The changing character of precipitation. Bulletin of the American Meteorological Society. 2003 Sep;84(9):1205-18.

[67]. Fu Q, Feng S. Responses of terrestrial aridity to global warming. Journal of Geophysical Research: Atmospheres. 2014 Jul 16;119(13):7863-75.

[68]. Meehl GA, Stocker TF et al. IPCC fourth assessment report (AR4). Climate change, the physical science basis. Chapter 10: global climate

projections. Cambridge University Press New York. 2007. p. 747–846.

[69]. Giorgi F, Im ES, Coppola E, Diffenbaugh NS, Gao XJ, Mariotti L, Shi Y. Higher hydroclimatic intensity with global warming. Journal of Climate. 2011 Oct;24(20):5309-24.

[70]. Shukla S, Safeeq M, AghaKouchak A, Guan K, Funk C. Temperature impacts on the water year 2014 drought in California. Geophysical Research Letters. 2015 Jun 16;42(11):4384-93.

[71]. Dai A. Increasing drought under global warming in observations and models. Nat Clim Chang. [Internet]. Nature Publishing Group; 2013:3:52–8.

[72]. Huang J, Yu H, Guan X, Wang G, Guo R. Accelerated dryland expansion under climate change. Nat Clim Chang. [Internet]. Nature Publishing Group; 2016 [cited 2018 Jan 17];6:166–71.Available from: http://www.nature.com/ articles/ nclimate2837.

[73]. Feng S, Fu Q. Expansion of global drylands under a warming climate. Atmos Chem Phys. [Internet]. 2013 [cited 2018 Apr 4];13:10081–94. Available from:www.atmos-chem-physdiscuss.net/ 13/146 37/ 2013/.

[74]. Trenberth KE, Shea DJ. Relationships between precipitation and surface temperature. Geophysical Research Letters. 2005 Jul 28;32(14).

[75]. Seneviratne SI, Corti T, Davin EL, Hirschi M, Jaeger EB, Lehner I, Orlowsky B, Teuling AJ. Investigating soil moisture–climate interactions in a changing climate: A review. Earth-Science Reviews. 2010 May 1;99(3-4):125-61.

[76]. Seneviratne SI, Lüthi D, Litschi M, Schär C. Land–atmosphere coupling and climate change in Europe. Nature. 2006 Sep;443(7108):205.

[77]. Scholze M, Knorr W, Arnell NW, Prentice IC. A climate-change risk analysis for world ecosystems. Proceedings of the National Academy of Sciences. 2006 Aug 29;103(35):13116-20.

[78]. Hirschi M, Seneviratne SI, Alexandrov V, Boberg F, Boroneant C, Christensen OB, Formayer H, Orlowsky B, Stepanek P. Observational evidence for soil-moisture impact on hot extremes in southeastern Europe. Nature Geoscience. 2011 Jan;4(1):17.

[79]. Mueller B, Seneviratne SI. Systematic land climate and evapotranspiration biases in CMIP5 simulations. Geophysical research letters. 2014 Jan 16;41(1):128-34.

[80]. Zscheischler J, Seneviratne SI. Dependence of drivers affects risks associated with compound events. Science Advances. 2017 Jun 1;3(6):e1700263.

[81]. Mishra V, Mukherjee S, Kumar R, Stone DA. Heat wave exposure in India in current, 1.5 C, and 2.0 C worlds. Environmental Research Letters. 2017 Dec 15;12(12):124012.

[82]. HortonRM, MankinJS, Lesk C,CoffelE, Raymond C.A review of recent advances in research on extreme heat events. Curr Clim Chang Rep. [Internet]. Springer International Publishing; 2016 [cited 2018 Jan 25];2:242–59. Available from: http://link. springer.com/10.1007/s40641-016-0042-x.

[83]. Ignaciuk A, Mason-D'Croz D. Modelling adaptation to climate change in agriculture. 2014.

[84]. OECD. Agriculture and Climate Change. Trade and Agriculture Directorate 2015. [http://www.oecd.org/tad/sustainable-agriculture/ agriculture-and-climate-change.htm].

[85]. Stinchcombe JR, Hoekstra HE. Combining population genomics and quantitative genetics: finding the genes underlying ecologically important traits. Heredity. 2008 Feb;100(2):158.

[86]. Keurentjes JJ, Koornneef M, Vreugdenhil D. Quantitative genetics in the age of omics. Current opinion in plant biology. 2008 Apr 1;11(2):123-8.

[87]. Des Marais DL, Hernandez KM, Juenger TE. Genotype-by-environment interaction and plasticity: exploring genomic responses of plants to the abiotic environment. Annual Review of Ecology, Evolution, and Systematics. 2013 Nov 23; 44:5-29.

[88]. Roy SJ, Tucker EJ, Tester M. Genetic analysis of abiotic stress tolerance in crops. Current opinion in plant biology. 2011 Jun 1; 14(3):232-9.

[89]. Manolio TA. Genomewide association studies and assessment of the risk of disease. New England journal of medicine. 2010 Jul 8; 363(2):166-76.

[90]. Bush WS, Moore JH. Genome-wide association studies. PLoS computational biology. 2012 Dec 27; 8(12):e1002822.

[91]. Thoen MP, Davila Olivas NH, Kloth KJ, Coolen S, Huang PP, Aarts MG, Bac- Molenaar JA, Bakker J, Bouwmeester HJ, Broekgaarden C, Bucher J. Genetic architecture of plant stress resistance: multi- trait genome- wide association mapping. New Phytologist. 2017 Feb; 213(3):1346-62.

[92]. Wan H, Chen L, Guo J, Li Q, Wen J, Yi B, Ma C, Tu J, Fu T, Shen J. Genome-wide association study reveals the genetic architecture underlying salt tolerance-related traits in rapeseed (*Brassica napus* L.). Frontiers in plant science. 2017 Apr 26;8:593.

[93]. Lafarge TC, Bueno J, Frouin L, Jacquin B, Ahmadi CN. Genome-wide association analysis for heat tolerance at flowering detected a large set of genes involved in adaptation to thermal and other stresses. PLoS ONE. 2017, 12: e0171254.

[94]. Chen J, Chopra R, Hayes C, Morris G, Marla S, Burke J, Xin Z, Burow G. Genome-wide association study of developing leaves' heat tolerance during vegetative growth stages in a sorghum association panel. The plant genome. 2017 Jul 1;10(2).

[95]. Shah SH, Ali S, Hussain Z, Jan SA, Ali GM. Genetic Improvement of Tomato (*Solanum lycopersicum*) with AtDREB1A Gene for Cold Stress Tolerance using Optimized Agrobacterium-mediated Transformation System. International Journal of Agriculture & Biology. 2016 May 1;18(3).

[96]. Riechmann JL, Meyerowitz EM. The AP2/EREBP family of plant transcription factors. Biological chemistry. 1998 Jun 1; 379:633-46.

[97]. Nejat N, Mantri N. Plant immune system: crosstalk between responses to biotic and abiotic stresses the missing link in understanding plant defence. Signal. 2017 Jan 1;2:O2.

[98]. Licausi F, Giorgi FM, Zenoni S, Osti F, Pezzotti M, Perata P. Genomic and transcriptomic analysis of the AP2/ERF superfamily in *Vitis vinifera*. BMC genomics. 2010 Dec; 11(1):719.

[99]. Liu W, Yuan JS, Stewart Jr CN. Advanced genetic tools for plant biotechnology. Nature Reviews Genetics. 2013 Nov; 14(11):781.

[100]. Abdelrahman M, El-Sayed M, Sato S, Hirakawa H, Ito SI, Tanaka K, Mine Y, Sugiyama N, Suzuki M, Yamauchi N. RNA-sequencing-based transcriptome and biochemical analyses of steroidal saponin pathway in a complete set of Allium fistulosum—A. cepa monosomic addition lines. PLoS ONE. 2017:12: e0181784.

[101]. Flint-Garcia SA. Genetics and consequences of crop domestication. Journal of Agricultural and Food Chemistry. 2013 Jun 14;61(35):8267-76.

[102]. Abdelrahman M, Al-Sadi AM, Pour-Aboughadareh A, Burritt DJ, Tran LSP. Genome editing using CRISPR/Cas9–targeted mutagenesis: An opportunity for yield improvements of crop plants grown under environmental stresses. Plant Physiol. Biochem. 2018: 131: 31–36.

[103]. Taranto F, Nicolia A, Pavan S, De Vita P, D'Agostino N. Biotechnological and digital revolution for climate-smart plant breeding. Agronomy. 2018 Dec; 8(12):277.

[104]. Kamburova VS, Nikitina EV, Shermatov SE, Buriev ZT, Kumpatla SP, Emani C, Abdurakhmonov IY. Genome editing in plants: An overview of tools and applications. Int. J. Agron. 2017: 1–15.

[105]. Zhu C, Bortesi L, Baysal C, Twyman RM, Fischer R, Capell T, Schillberg S, Christou P. Characteristics of genome editing mutations in cereal crops. Trends in plant science. 2017 Jan 1; 22 (1) :38-52.

[106]. Abdelrahman M, Jogaiah S, Burritt DJ, Tran LS. Legume genetic resources and transcriptome dynamics under abiotic stress conditions. Plant, cell & environment. 2018 Sep; 41(9):1972-83.

[107]. Hussain B, Lucas SJ, Budak H. CRISPR/Cas9 in plants: at play in the genome and at work for crop improvement. Briefings in functional genomics. 2018 Apr 17; 17(5):319-28.

[108]. Lino CA, Harper JC, Carney JP, Timlin JA. Delivering CRISPR: a review of the challenges and approaches. Drug delivery. 2018 Jan 1; 25(1):1234-57.

[109]. Larochelle S. Genomics: CRISPR–Cas Goes RNA. Nature Methods. 2018 Apr 27;15(5):312.

[110]. Haque EH, Taniguchi MM, Hassan P, Bhowmik MR, Karim M, ´Smiech K, Zhao M, Rahman and Islam T.. 2018. Application of CRISPR/Cas9 Genome Editing Technology for the Improvement of Crops Cultivated in Tropical Climates: Recent Progress, Prospects, and Challenges. Front. PlantSci. 9: 617.

[111]. Shen C, Que Z, Xia Y, Tang N, Li D, He R, Cao M. Knock out of the annexin gene OsAnn3 via CRISPR/Cas9-mediated genome editing decreased cold tolerance in rice. Journal of Plant Biology. 2017 Dec 1;60(6):539-47.

[112]. Shimatani Z, Kashojiya S, Takayama M, Terada R, Arazoe T, Ishii H, Teramura H, Yamamoto T, Komatsu H, Miura K, Ezura H. Targeted base editing in rice and tomato using a CRISPR-Cas9 cytidine deaminase fusion. Nature biotechnology. 2017 May; 35(5):441.

[113]. World Agroforestry Centre. Surviving drought through agroforestry. 2012. Retrieved from: http://worldagroforestry.org/newsroom/highlights/surviving--- drought--- through agro forestry.