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REVIEW ARTICLE

CLIMATE READY CROPS FOR DROUGHT STRESS: A REVIEW IN NEPALESE CONTEXT

Suman Bagale*

Institute of Agriculture and Animal Science, Tribhuvan University, Kathmandu, Nepal.

**Corresponding Author Email: sumanbagale74@gmail.com*

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ABSTRACT

The global population is increasing at an alarming rate. Meeting food and nutritional demand of this increased population has become a major issue for agronomist and agricultural researchers. On the top of that, overall agricultural productions are constrained by global climate change resulting several biotic and abiotic stress. Among the abiotic stress, drought has become a problematic issues in arid and semi-arid regions of the world leading towards the dire future, questioning on food sufficiency and affordability for future world. Though several adaptation and mitigation strategies are practiced at local and global level, these seems redundant with increased demand of foods crops. To address the problem of climate change on drought in a sustainable way, climate ready crops are been developed through selection, breeding and genetic engineering techniques. These crops are tailored for drought prone areas pooling all the traits that are responsible for tolerating the water stress condition. This review article discuss some of the released climate ready crops, their xerophytic traits and mechanism of gene expression of such crops. Climate ready crops seems to surpass the effect of climate change on drought stress through sustained productivity that could meet the need of future generation. Development and management of these crops could help to maintain the stability on food production that could become a real boon for agriculture which is hindered by climate change.

KEYWORDS

Abiotic, arid, food, genetic engineering, stress, xerophytic.

1. INTRODUCTION

The global population is increasing in rapid pace, which has posed a serious question for food security in near future. The population around the world is expected to raise 9.3 billion by 2050, this exponential growth of population is far ahead than the world cereal yields that have been declined since 1961 (Security, 2013). Though the agro-technologies are developed to produce the food needed for future to ensure food security, this has posed a hindrance by global issues such as climate change and global warming. Climate change is likely to impair the pillar of food accessibility by increasing food price and reducing food production (Mendelsohn, 2008). Change in the climatic conditions such as temperature, wind composition, humidity and occurrence of natural calamities such as flood, landslide, and drought has negative impacts in agricultural productivity, thus making world more vulnerable to food unsecured conditions. Projected changes in agriculture are not only limited to increase in temperature and heat waves, large changes in the rainfall are also expected to occur which is likely to affect some regions from severe drought in near future (Mendelsohn, 2008). Drought stress causes imbalance in natural status of environment and drastically disrupts the crop cultivation ultimately threatening the food security (Jewell et al.,

2010; Rahman & Hasegawa, 2012). One of the reason for under nourishment, malnutrition and hunger is global and regional drought which has reduced the global food production by causing shortage of world grain (Kogan et al., 2019).

Plant growth and yield is severely affected by the inadequate supply of water which result in decreased carbon assimilates and highly susceptible to pest and diseases (Mangena, 2018). Depletion of soil moisture leads to pollen sterility, low assimilation, desiccation of plant tissue ultimately low production of grains. To cope with the problem of drought stress researchers are focusing for selection of genotypes for drought resistant traits to develop climate ready crops for drought prone areas. Climate ready crops respond well to the changed climatic conditions, these are developed through incorporation of superior genes that fits well under stress conditions. Climate ready crops are those crops which are tailored to particular climate to solve the existing problem within short period of time. As the climate is changing in rapid pace, there is need for development of climate ready crops to cope with problem within short period of time. The conventional breeding may not incorporate all the necessary traits within short period of time. So, the scientist are focusing on transgenic and genetic engineered plants to address the alarming issue

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of climate change by developing Climate Ready Crops. According ETC, a Canadian based organization till now 1663 patents of genetic engineered plant have been released as Climate Ready Crops with high tolerance for drought, heat, cold and salinity. (*Climate-Ready Crops: The Pros and Cons*, n.d.). Through farmers are practicing different adaptation and mitigation strategies to cope with climate change but the approaches does not seems sustainable for commercial production. Developing climate ready crops will surely help to combat the problem of drought, ensuring food security in the drought prone areas around the globe. So, to explore the climate ready crops in relation to drought stress, the present review was carried out with the following objectives:

- To understand the mechanism of climate ready crops for drought tolerant traits.
- To explore some of the released climate ready varieties of crops in Nepal
- To understand the selection and plant engineering of climate ready crops for drought prone areas.

2. CLIMATE READY VARIETIES FOR DROUGHT PRONE AREAS

Many researches have been conducted by NARC, IAAS, and Government program directorates to explore the crops which have good drought tolerant attributes. Most of the research are focused on adaptation trail and varietal screening for drought traits. These released varieties can perform well under water stressed conditions without decreasing yield significantly.

2.1 Rice (*Oryza sativa*)

Sahabhagi Dhan: This is one of the renowned climate ready variety of rice released in India. It showed good performance under transplanted conditions in low land and Direct seeding in rainfed upland condition. It needs only one or two irrigation to produce an average yield of 4.7 ton/ha. Sookhadhan-2: The original designation of Sookhadhan -2 is IR-74371-54-1. The variety matures in 121 DAS 4.96 ton/ha. The variety was released in 2011 with joint co-operation of International Rice Research Institute (IRRI) and Institute of Agriculture and Animal Science (IAAS). The variety was found to have average root length of 24.3cm.(B. B. Adhikari et al., 2018). Sookhadhan-1: The original designation of Sookhadhan-1 is IR-74371-46-1-1. The variety matures in 122 DAS producing average grain yield of 4.52 ton/ha and straw yield of 6.96 ton/ha. The variety was released in 2011 with joint co-operation of International Rice Research Institute (IRRI) and Institute of Agriculture and Animal Science (IAAS). The variety was found to have average root length of 23.5 cm.

Sookhadhan-3: The original designation of Sookhadhan-2 is IR-74371-70-1-1. The variety matures in 121 DAS producing average grain yield of 4.77 ton/ha and straw yield of 6.97 ton/ha. The variety was released in 2011 with joint co-operation of International Rice Research Institute (IRRI) and Institute of Agriculture and Animal Science (IAAS). The variety was found to have average root length of 23 cm. Hardinath-1: The original designation of Hardinath 1 is IR80411-B-49-1-1. The variety has plant height of 100cm and matures in 115 DAS. The variety was released in 2009 and recommended for Rainfed Lowland condition. Ghaiya-2: This variety of rice was originated in India and released in Nepal in year 1987. Variety measures an average plant height of 67.6 cm. The variety is recommended for upland rain fed condition. The variety matures at 113 DAS producing an average grain yield of 3.80 ton/ha and average straw yield of 10.49 ton/ha.(Adhikari, 2009). Tarahara 1: This variety was released in Nepal in 2010 with cultivation domain recommended for rain fed cropping pattern of Terai and Inner Terai. The variety matures at 113 -125 DAS producing an average grain yield of 4.2 ton/ha.

2.2 Maize (*Zea Mays*)

Deuti: The original designation of this variety is ZM-621. It was developed from SADV-1F1, which was originated in Zimbabwe. It was developed from technical assistance CYMMYT and released in 2006. It is recommended to cultivate in Mid hills of Nepal between an elevation of 1000msl to 2000msl. The breeding stock of this variety is maintained in

National Maize Research Program (NMRP) Rampur. The leaf sheath is absent in this variety. The variety matures in 130 DAS at an elevation of 1400msl and 150 days at an elevation of 1700msl producing an average grain yield of 5715 kg/ha. It is tolerant to varying degree of drought based on field observation.

Manakamana -5: This variety of maize is moderately tolerant to drought. It is originally designated as hill pool white. It was developed as a composite variety from 10 different released, promising and local landraces. It was released by NMRP, Rampur in 2010, recommending Mid hills (1000-200m) for cultivation domain. The breeder seed stock of this variety is maintained in RARS, Lumle. The variety matures in 130 DAS at an elevation of 1400msl and 145 DAS at an elevation of 1700msl producing an average yield of 5070kg/ha. Manakamana-6: This variety of maize is moderately tolerant to drought stress. Its original designation is Hill Pool Yellow. It was developed as a composite variety comprising of 12 different promising and landraces. It was released by NMRP, Rampur in 2010 and its breeding stock is maintained at Regional Agriculture Research Station (RARS), Lumle. It is recommended for Mid Hill for an elevation between 1000msl to 2000msl. The variety matures 130 DAS at 1400msl and 145 DAS at 1700msl with an average grain yield of 5130 kg/ha.

2.3 Wheat (*Triticum aestivum*)

Gautam: This variety is a drought tolerant variety of wheat was released in 2004 and recommended for rain fed condition of Terai, Tars, upto the elevation of 500msl from the sea-level. The variety matures at 114 DAS producing an average grain yield of 3.4 ton/ha. NL-1327: This genotype was originated in Mexico. It is found to perform good yield under drought condition with average yield of 2 ton/ha. The genotype matures in 110 days in rain fed condition.(Poudel et al., 2020)

2.4 Finger Millet (*Eleusine corocana*)

Dalle-1: Original Designation of the variety is IE-980. This variety was originated in India and was released in Nepal in 1980. The recommended domain is Terai and Mid-hill of Nepal. The breeder stock seed is maintained in Hill Crop Research Program (HCRP), Kavre. It has short height, closed head and synchronous maturity. This variety matures at 125 DAS in Terai and 151 DAS in Mid hill with average grain yield of 3300kg/ha.

Kavre Kodo-1: The original designation name of this variety is NF-6401-26. This variety is a local cultivar of Surkhet district, Nepal. It was released in 1990. The recommended domain of this variety is Rainfed Upland of Mid hills between 900msl to 1900msl. The breeding stock of this variety is maintained in HCRP, Kavre. It has 6-7 open erect fingers and matures synchronously. The variety matures at 151-162DAS producing an average grain yield of 1.83-4.83 ton/ha.

Kavre Kodo-2: The original designation of this variety is GE-5176. It was developed in India by SAARC-RVT institute and released in Nepal in 2015. It can be cultivated in from mid hills to high hills of Nepal between an elevation of 700-1800msl. The breeder stock seeds are maintained in HCRP, Kavre. It has compact ear head with synchronous maturity. The variety matures at 153 DAS from planting producing an average grain yield of 2530kg/ha.(Joshi et al., 2016)

Okhle-1: The original designation name of this variety is NE1304-43. Its pedigree is selected from local cultivar of Okhaldhunga and released in 1980. This variety is recommended for mid hills and high hills of Nepal. Its breeding stock is maintained in HCRP, Kavre. It is characterized having 7 semi-erect fingers resembling bell shaped head during physiological maturity. This variety matures at 154 DAS in Mid-hills and 194 DAS at High hills producing an average grain yield of 3300kg/ha.

2.5 Foxtail Millet (*Seteria italica*)

Seto Kaguno: It is the promising variety of Foxtail Millet with pronounced drought tolerant traits. Its original designation is C-5644. Its pedigree is considered to be landraces of kaguno from Lamjung district. It was developed by NARC and recommended for cultivation in Mid hills and High hills of Nepal. The variety is erect and geniculate with distinguishing white

straw color. The variety matures at 90 days from planting producing an average grain yield of 2.5-3.5 ton/ha.

Kalo Kaguno: It was developed from landraces of Kagulo found in Humla district of Nepal. The breeding stock of this variety is maintained in NARC. It is recommended for Mid hills and High hills of Nepal. The grain color is black with distinguishing brown panicle color at maturity. This variety matures at 100 days from planting producing an average grain yield of 2.5-3.5ton/ha.(Joshi et al., 2016)

3. SUITABLE IDEOTYPES OF CLIMATE READY CROPS

Water is needed for growth, survival and reproduction of plants. Water stressed condition in plant may lead to complete failure of crops or causes significant decrease in the yield. Some plant develops special mechanism by changing morphology, physiology to cope with water stress. However, the ability of plants to cope with water stress condition depends upon plant species, growth stages, duration and intensity of water deficit(Jaleel et al., 2008). Plants undergo several morphological, anatomical and physiological changes when exposed to dry or hot conditions(Mangena, 2018). Moisture deficiencies induces different morphological changes in plant which are critical to respond to drought stress ranging from morphological adaptation to physiological and metabolic responses(Hund et al., 2009). The ideotypes mainly deals with the morphological adaptations of plants in response to drought stress conditions.

3.1 Root Morphology

Several study indicates that, plant root system play important role in plant adaptation to drought habitat (Pu et al., 2010).The proliferous root growth helps to draw the water from deeper profile and ensure plant survive under moisture stress conditions. In rice plants root length and root weight are the indicators of drought tolerance as it helps to absorb water from deeper depth helping plant to survive under drought stress condition(Adhikari et al., 2018). Roots adapted to drought stress conditions have diffused root hairs, with greater biomass to increase the surface area for absorption of water and nutrients.

3.2 Leaves Morphology

Leaves are the active sites for photosynthesis and transpiration. Plants in water deficit conditions modify their leaves to cope with drought stress. Plants grown in dry areas tend to have thick leaf surface and cuticle to reduce the transpiration loss. Likewise, some leaf modifications such as epidermal hairs can be seen to amplify the hygroscopic mechanism to conserve water. Under water stress condition plant develops xeromorphic characters to reduce transpiration which is achieved through leaf shedding, decreasing leaf number and leaf size. (Basu et al., 2016). Leaves adapted to drought stress have thick layers of epidermal sources lined with waxy layers of cuticle. Under water stress condition some plants roll their leaves to conserve the moisture loss by evaporation and transpirations.

3.3 Stem Morphology

Plant grown under water stress conditions tends to have thin stem with reduced stomata on the surface. Likewise, stems are provided with thrones and hairs to prevent water loss. The anatomy reveals that, drought tolerant plants tend to have enlarged xylem vessels in their stem. According to Specht et al. (2001) soybean grown under water stress condition have short stem length. In some cases, stem develops coating of waxy layers to prevent transpiration loss from stem.

4. MECHANISM OF CLIMATE READY CROPS TO COPE WITH DROUGHT STRESS

Crops species that are tailored for drought prone area should be drought resistant. Drought resistant is border term for trait of a plant to endure with water stress condition. A plant can have their initiate mechanism for coping with long- and short-term drought. Plant uses drought escaping, drought avoidance or drought tolerance mechanism based on the physiology of plant.

4.1 Drought Escape

Drought escape is ability of a plant to complete its lifecycle before the onset of drought.(Basu et al., 2016). They do not experience water stress condition as they are able to modify their vegetative and reproductive growth according to the water availability essentially through two different mechanisms: Rapid phenological development and Developmental plasticity. (Jones et al., 1981). Rapid Phenological Development involves the rapid growth of plant tissues and parts and production of minimal number of seeds before the start of drought conditions. Plant do not have any specialized structure for physical, morphological or biochemical adaptations. Plants with development plasticity mechanisms produces little growth and small number of seeds and flowers during the dry conditions whereas in wet conditions they show profuse growth and produce large number of seeds. Drought escaping mechanism is only beneficial in natural conditions, so that breeders don't focus on this mechanism for engineering of climate ready crops for drought resistant traits.

4.2 Drought Avoidance

It is a mechanism of plant to maintain high amount of tissue water during water stress condition. It is achieved through a variety adaptive traits involving minimization of water loss traits called water savers or optimization of water intake called water spenders.(Basu et al., 2016). Water savers minimizes the loss of water from the leaves and tissues through reduced transpiration and evaporation. Physiology guides the stomatal regulation in water savers. Water spenders have mechanism to uptake water through increased root rooting and hydraulic conductance.

4.3 Drought Tolerance

Drought tolerance is the ability of plant to endure the water stress condition without any significant decrease yield. The adaptive traits involves maintenance of cell turgor pressure through osmotic regulation, cellular elasticity and increasing protoplasmic resistance. (Morgan, 1984)

5. PLANT ENGINEERING FOR CLIMATE READY CROPS FOR DROUGHT STRESS

The disease resistance gene in a plant can be incorporated through conventional breeding methods such as selection, pedigree breeding, quotatives trait locus mapping and genetic engineering. Selection practices such as Marker Assisted Selection (MAS) and Genetic Modification (GM) techniques are widely used for engineering of climate ready crops as these techniques allows pooling of all the desirable traits in short period of time. Several drought resistant transgenic plants including rice, tomato, soybean, maize, barley have been developed using gene encoding proteins that control the drought regulatory networks. (Nagargade et al., 2017). In contrast to conventional breeding, transgenic technique seems to be a more attractive approach which allows the direct induction of a single or group of desired genes(Gosal et al., 2009). In transgenic breeding, multiple genes are involved for the expression of drought resistant trait. The drought resistant gene of interest is incorporated in the variety for its expression.

The main interest in engineering climate ready crops for drought resistant traits are focused on increasing Water Use Efficiently (WUE),that can be achieved by two different mechanism. The first is inserting genes for compatible osmolites such as sugar, amino acids. The next approach is constitutive overexpression of embryonic proteins which provides dehydration tolerance. First group of genes are involved in cellular proctants, commonly called Osmoproctants Mechanism. In this mechanism, osmoproctants such as Proline, Mannitol, Trehylose, Glycerin betaine are formed which protects plants from dehydration during water stress conditions. This mechanisms focus on activating of genes, which produces the enzymes needed for regulation and formation of these osmoproctants. The higher accumulation of these compounds by transferring genes in transgenic wheat plays a critical role in improving drought tolerance (Zhu et al., 2005). Overexpression of Proline in Tomato and Tobacco make them tolerant to drought stress. In plants, proline is

synthesized from glutamate through the glutamate pathway.

The reduction of glutamate to its semialdehyde is catalyzed by P5CS (Δ^1 -pyrroline-5-carboxylate synthase) enzyme, which then reduces to proline. P5CS is a rate-limiting enzyme for the synthesis of proline by feedback inhibition of P5CS (Zhang et al., 1995). For instance, the maize variety DroughtGard™ released in USA in 2013 was developed by using osmoprotectants engineering of trehalose macromolecule. Likewise, using Cold Shock Proteins (CSPs) genes from bacteria *E. coli* conferred resistant to drought stress and improved grain yield in maize crops under drought conditions (Castiglioni et al., 2008). Second mechanism focuses on use of transcription factors. Plants induce the expression of various transcription factors to cope with environmental stress (Khan et al., 2019). Transcription factors and the signaling molecules are the components that bind with enhancer or promoter region of genes during gene expression. Some of the transcription factors used in transgenic breeding are Dehydration Responsive element binding (DREB), WARKY2 proteins, a 60 amino acids for repressor and activator of genes for drought tolerance, HDG11 Expression of numerous genes responsive to drought.

6. CONTROVERSIES ON CLIMATE READY CROPS

Climate ready genes make farmers more dependent on Genetically Modified Plants that can jeopardize the biodiversity and threaten the global food sovereignty. New seeds must be purchased every year, due to this farmer must pay royalties to use them. A promising case that Monsanto (Organization working in production of Climate Ready Crops) had filled 112 lawsuits against farmer for Patent Infringement in 2007. Controlling inserted genes has become problem. No option for differential expression of genes at different stages. The mechanism of expression of "Cold Shock Protein" transferred from Bacteria is poorly understood. CSP aids bacteria to withstand sudden cold shock, but in crops it helps to tolerate drought stress. Hypothesis on RNA folding mechanism are proposed but left researcher space for further research.

A study on maize was done where maize doesn't seem to use water more efficiently nor it has made crop more resilient, it only made the maize plant tolerate drought stress using bacterial mechanisms. Controversy case of WEMA (Water Efficient Maize for Africa), where organizations like BASF and Monsanto are involved in breeding for Climate ready crops. The project had utilized Marker Assisted Selection (MAS) as conventional breeding approach and Genetic Engineering as transgenic breeding. But the project has announced that the variety developed by conventional breeding could be released within 6 years but the variety developed through genetic engineering can take a releasing time of 10 years. This has posed the serious question on redundancy of Genetic Engineering in development of Climate Ready Crops.

7. CONCLUSION

Climate ready crops can be only option for uplifting the grain production in drought prone areas. Engineering of plants for developing climate ready crops can combat with the impending food insecurity in this era where population is increasing in alarming rate. The crops attributes in mechanisms of gene expression in drought stress condition and adapted morphology of crops for drought tolerant mechanism should be evaluated for developing suitable climate ready crops in drought prone areas. Evaluation of landraces and modern varieties possess the superior genes for drought tolerance, such landraces should be conserved and utilized for further breeding programs. Climate ready crops can perform well under stress condition along with maintaining production sustainability. Likewise, different adaptation and mitigation mechanism should be followed in local level to combat with climate change. The researches on drought stress gene expression, marker assisted selection, and root profiling can help to garner the knowledge for future research focusing on drought stress in response to changing climate.

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