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4. Climate Resilience of Millets in Times of Global Warming

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Abstract:

Millets are climate resilient small seeded grain crops cultivated worldwide in arid and semiarid regions. These are the crops which outperform all the other most dominating cereals crops of the world. Climate change has induced many biotic and abiotic stresses, which has posed a serious threat to agriculture production. The most promising cause of climate change is global warming, i.e., the increase in the overall temperature of the earth due to the absorption of heat by greenhouse gases such as CO2, CH4, N2O etc. This global warming has caused serious implications in the climate of the surroundings, witnessed as the change in precipitation pattern (prolonged drought in some areas and waterlogging stress in others), increased temperature stress and lodging, increased pest attack etc. These widespread issues have been successfully resolved by the cultivation of millets. This chapter discusses the serious implications of climate change, how millets are the best alternative in this era of climate change, the climate-resilient features of millets, along with their nutritional benefits and the mechanism of climate resilience of millets. The millets are inherently resilient to changing climatic conditions owing to their special morphological features and easy adaptation. The climate resilience of millet crops can further be enhanced by various newly merging techniques, such as the application of PGPRs and Cas9 technology. The climate resilience of millets is one property of millets that has made them the most reliant crops in this modern era of development. Sustainable agriculture production thus needs the cultivation of these crops to meet global food security.

Keywords:

Cas9 technology, Climate resilience, Global warming, Millets, PGPR, Sustainable agriculture.

4.1 Introduction:

One of the most pressing issues confronting the modern world is feeding everyone on the planet. The risk of global warming as well as a changing climate scenario persists even while some of these causes of hunger can really be tackled, leading to a slight drop in the total number of people that are suffering from malnutrition and starvation from approximately 1.0 billion during 1990–1992 to 850 million in 2010–2012 [1]. Estimates indicate that between 2-3 billion individuals may face hunger and food insecurity in 2050 as just a consequence of diminishing agricultural rate of production and further stress of sustaining a population approaching 9 billion [2,3]. Global warming presents agricultural experts with a new worldwide issue, impacting practically all climatic factors, such as air temperature, rainfall intensity and dispersion. Throughout the previous 65 years, there have been substantial changes in the world, including global warming as well as the anticipated and witnessed climate changes for such twenty-first decade. Climate change is a complex intergovernmental issue that affects a number of biological, environmental, socio-political, and socioeconomic fields on a global scale [4,5].

Recent years have seen the changing climate and also its unpredictability as significant obstacles to Indian agriculture. The worldwide climate change projections involve rising average temperatures, rainfall, and an increase in extreme weather events like flooding and heat waves, as well as increased levels of carbon dioxide in the atmosphere and ground-level ozone concentrations and rising sea level that will cause coastal areas to become submerged. It has become more evident recently as different regions of the nation have experienced climate disasterslike droughts, excessive rain, floods, cyclones, frost andheat waves Etc.

The expected implications of climate change on agriculture production, natural ecosystems, water resources and food security were detailed in the IPCC's fourth and fifth reports [6]. Climate change including rising worldwide mean temperaturesare thought to have a direct effect on agricultural productivity, yields, and the food system's sustainability. Whereas climate change may assist certain places by increasing production and output, this is unlikely to be sufficient to feed the world's rising population [7]. Moreover, the majority of academics predict that present levels of global warming and emissions of greenhouse gases would drastically diminish crop output. As a result, sustaining food security is heavily dependent on decreasing emissions of greenhouse gases in order to regulate global temperatures. Nevertheless, the agricultural sector is a significant generator of greenhouse gases, most importantly methane in the environment.

Increment of greenhouse gases, like carbon dioxide, methane, nitrous oxide, etc., are merely a result of inefficient agricultural practices, such as intensive tilling and burning of crop residues, which also negatively influence the productivity of both land and water. According to one prediction, worldwide surface air temperatures may rise by 4.0–5.8 °C in the future decades, counteracting the expected advantages of rising atmospheric carbon dioxide concentrations on crop plants. New environmental circumstances developed across time and space, which may be to blame for periodic droughts, rising temperatures, flooding, salinity, rising carbon dioxide levels, rising sea levels, and unpredictable rainfall patterns [8].

Global climate change has a large impact on agricultural production all around the world. Additionally, it directly affects biophysical elements like animal and plant growth as well as many aspects of food processing and distribution. To maximize agricultural production and satisfy the rising population's food needs, it is essential to assess the impacts of worldwide climate change and apply new tools and strategies to decrease their influence.

In this context, millets are the most valuable crop since they are nutritionally climate change-tolerant and have a very high potential for marginal areas to produce more significant economic returns than other millet, even in climate change with extreme temperature conditions. However, it has higher grain yield ceiling temperatures and serves as a crop with enormous nutritional quality that must be fully realized [9].

Since millet crops are more resistant to extreme climatic occurrences like drought and water scarcity, they can be extremely important in providing food and nutritional security in situations when the climatic environment is changing at an alarming rate. Millets are mostly grown on marginal lands in a rainfed environment.

They may continue to grow and yield sufficient grains even in drought-affected regions with an average precipitation of around 250 mm. Because of its distinctive qualities, which include the C4 plant's high photosynthetic efficiency, greater capacity for producing dry matter, and ability to survive in challenging agro-climatic situations with fewer number of inputs and greater economic returns, it outperforms as compare to all other cereals, including rice [10], wheat [11], maize, barley and sorghum [12].

Resilience is an emergent feature, and stress tolerance requires the coordinated deployment of dozens to hundreds of molecular or phenotypic modifications [13]. While cultivated and wild grasses share some resilience characteristics, others are unique to millets and their stress-tolerant cousins.

All millets and many types of grass use the enhanced C4 photosynthesis pathway, which lowers photorespiration and increases water use effectiveness, allowing millets to flourish in hot and arid regions.

Because C4 plants have "Kranz" anatomy in their leaves, they can fix inorganic CO_2 better and use water more effectively than C3 plants. It also has several benefits, including fast maturation, resilience to drought, low input requirements, and a general lack of biotic and abiotic stressors.

4.2 Different Climate-Resilient Millets and Their Benefits:

Millets are round, small-seeded whole grains that are commonly farmed as cereal crops or grains for livestock feed and human use. They are non-glutinous and easy to digest, making them non-allergenic, and they have a great nutritional profile. Compared to other grains, millets are a rich source of nutrients, particularly phosphorus, potassium, calcium, and magnesium.

Although all millet types are members of the *Poaceae* family, they vary in terms of colour, species, and other distinctive qualities. Major and minor millets are two classifications that have been created based on the crop's popularity and level of cultivation.

They fall into two broad categories; sorghum and bajra are the main millets, whereas barnyard, foxtail, kodo, proso, little and finger millet are minor millets (**Figure 4.1**).

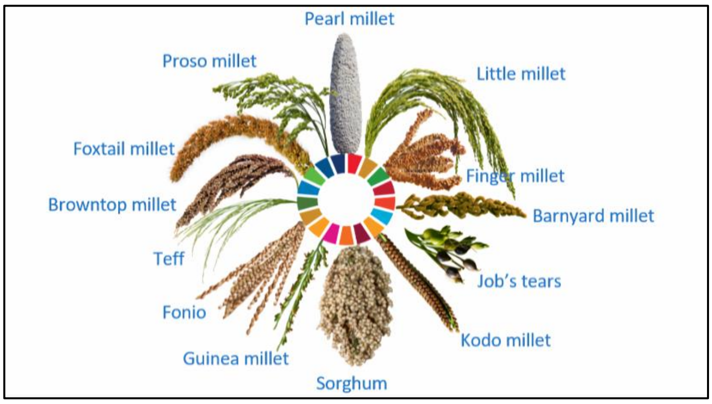

Figure 4.1: Different Kinds of Climate Resilient Millets

4.2.1 Sorghum:

In India and Africa, sorghum is a typical ancient cereal grain. It is considered the most incredible alternative for celiac disease. Over 16 million ha of sorghum were grown in India in 1981, but that number gradually dropped to 7.8 million ha in 2007–2008, still accounting for 20% of the world's production in recent years. Sorghum works even better when used in place of wheat to make products like bread, pasta, biscuits, Etc. Ajono is a beverage that East Africans have traditionally prepared from sorghum millet. Sorghum crop can withstand drought conditions because of their deep root system, waxy leaves, and stem that contain mortar cells. It is more suited to dryland conditions compared to all cereal crops because it can survive greater temperatures at any stage of growth [14].

Benefits:

- Iron, calcium fibre, protein, and wax policosanols, all of which are found in sorghum, can help in lower cholesterol levels and provide other health advantages.
- For people with celiac disease or others who cannot tolerate items made from wheat, sorghum provides gluten-free grain.
- Most sorghum protein is prolamin (kafirin), with the unique trait of diminishing digestibility while cooking, so it can be advantageous in some dietary groups.
- Protein, fibre, thiamine, riboflavin, folic acid, and carotene are all abundant in them. With adequate levels of iron, zinc, and sodium, it is rich in potassium, phosphorus, and calcium [15].

4.2.2 Pearl Millet:

Pearl millet (*Pennisetum glaucum* L.), often called as Bajra. Throughout the last three years, India has been the most significant producer of pearl millet in Asia, producing 8.3 million tonnes with an average productivity of 930 kg/ha. Pearl millet has high protein content (12–16%) as well as low-fat content (4-6%). The amount of dietary fibre in it is 11.5%.

Pearl millet has the highest niacin level of any cereal. Foliate, magnesium, iron, copper, zinc and vitamins E and B complex are also present. Compared to other millets, it contains a lot of energy. Moreover, it contains a lot of healthy unsaturated fats and calcium. It is high in fat, magnesium, and insoluble fibre.

Its flour has poor storage quality, an unpleasant flavour, and a nutty taste due to the lipase enzyme [17]. It is ideally suited for arid areas due to its capacity to use water more efficiently than sorghum or maize. Nevertheless, unlike sorghum, it cannot withstand drought or water stress, but it can abbreviate its life cycle and flower earlier under such conditions.

This is referred to as the drought escape mechanism. Pearl millets were commonly cultivated in areas with poor soils and low average rainfall of 200–500 mm [18].

Benefits:

- Pearl millet has insoluble fibre, which aids in the decrease of excess bile, which leads to gallstones.
- It aids in the treatment of respiratory diseases and migraines.
- Food moves through the gut more slowly as a result. Hence, lessen the risk of inflammatory bowel illness.

4.2.3 Finger Millet:

Finger millet (*Eleusine coracana* L.), commonly called as Ragi, was previously considered a minor millet, but its increased adaptability has made it considerably more prevalent among cereals. It is one of the most valuable nutritional cereals. It contains the amino acid (methionine) as well as iron, calcium, fibre, protein (6–8%), and other nutrients which have been missing from the diet of poor people who have survived on starchy staples for a hundred years.

The most abundant source of calcium is finger millet (300–350 mg/100 g). Finger millet is utilized in Nepal to produce the fermented beverage known as a bear. It is the cereal with the highest tolerance to salinity.

Benefits:

- Constipation, anaemia, high blood pressure, asthma, and heart issues can all be avoided with its aid [16].
- Cakes, custard, and porridge are just a few of the delicious and healthy foods that can be made with finger millet.
- It is nutrient-rich and aids in fighting malnutrition and degenerative diseases and raising haemoglobin levels.
- The grains of finger millets are fully recognized for their extreme usage as weaning feeds and have good malting qualities.
- It has strong antioxidant properties.

4.2.4 Proso Millet:

Proso millet (*Panicum miliaceum* L.) has the most excellent protein content (12.5%). It contains a lot of carbohydrates and fatty acids. It is a less expensive source of manganese than other traditional sources such as spices and nuts. The specific features of proso millet contribute to its health benefits. It is a rapid or emergency irrigated crop with minimal moisture needs. It is a low-demanding crop without any recognized illnesses. Proso millet grows well in a variety of soil types and climates.

Benefits:

- Proso millet contains a high concentration of niacin (Vitamin B3), which aids in the prevention of pellagra. Pellagra is a skin disease.
- It also contains protein, calcium for bone strength, and fluoride for dental health.
- It is high in calcium, which is necessary for bone formation and maintenance.
- It lowers cholesterol levels while also lowering the risk of heart disease.

4.2.5 Kodo Millet:

The coarsest cereal in the world is kodo millet (*Paspalum scorbiculatum* L.). Almost 3,000 years ago, in India, kodo millet was domesticated. It can be found in humid tropics and subtropical regions. Kodo millet contains a high concentration of B vitamins, particularly niacin, pyridoxine, and folic acid, as well as minerals such as calcium, iron, potassium, magnesium, and zinc. It is high in protein (11%), low in fat (4.2%), and high in fibre (14.3%). It is a minor grain crop that has exceptionally high levels of fiber, antioxidants, and phytochemicals [19].

It is thought to have the best drought resistance of such minor millet and also to yield well with a growing time of 80-135 days. It can survive in both deep as well as shallow soil.

Benefits:

- It is a traditional cuisine that resembles rice and is easily digestible.
- It also aids in preventing women's menstruation and joint and knee pain.
- It includes a lot of lecithin and is great for strengthening nervous system.

4.2.6 Foxtail Millet:

German and Italian millet are other names of foxtail millet (*Setaria italica* L.). Under low precipitation, it is growing in both the tropics and the temperate zones. It contains minerals like copper, iron and a lot of carbohydrates. It has twice the protein content as compared to rice. It has a quick ripening process and high photosynthetic efficiency, making it ideal for use as a catch crop. It can provide a high yield with a single pre-sowing rain [20]. According to [21], this crop uses less water than maize and sorghum.

Benefits:

- It is full of nutrients, has a sweet, nutty taste, and is one of the most easily digestible and non-allergenic cereals.
- Because of its magnesium concentration, foxtail millet aids in the prevention of diabetes by lowering blood glucose levels.

4.2.7 Little Millet:

Little millet (*Panicum sumatrense*) is a species of millet in the *Poaceae* family. It is referred to as a little but not less than its nutritional worth because it contains vitamins, minerals, and vital fatty acids for the body. Because of its high fiber content, little millet is an excellent substitute for rice in pongal or kheer. It grows quickly and is drought and water-logging resistant [22]. The grains are comparable to rice grains. Because of its high fiber content makes it a healthier alternative to rice. B vitamins and minerals such as calcium, iron, zinc, and potassium are abundant.

- It has high iron content.
- It aids in the prevention of obesity.
- It has a high level of antioxidant activity.
- It contains approximately 38% dietary fiber.

4.2.8 Barnyard Millet (Sanwa):

Barnyard millet (*Echinochloa frumentacea* L.) is a kind of millet that is commonly produced in India, China, Japan, Pakistan, Africa, and Nepal. It is the most abundant source of crude fiber and iron. Its grains contain various beneficial ingredients, such as gamma amino butyric acid (GABA) and beta-glucan, which are utilized as antioxidants and lower blood lipid levels. It is a drought-tolerant crop that can be produced in marginal soils, matures quickly, and has excellent nutritional value [23].

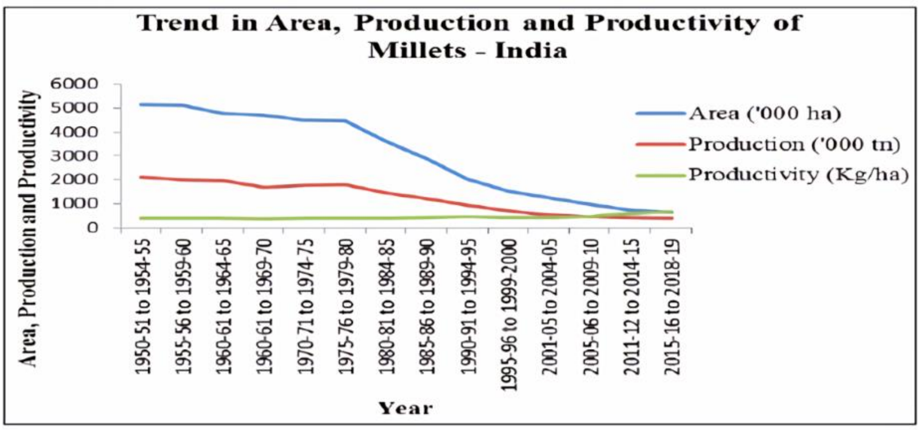

Figure 4.2: Area, Production and Productivity of Millets in India

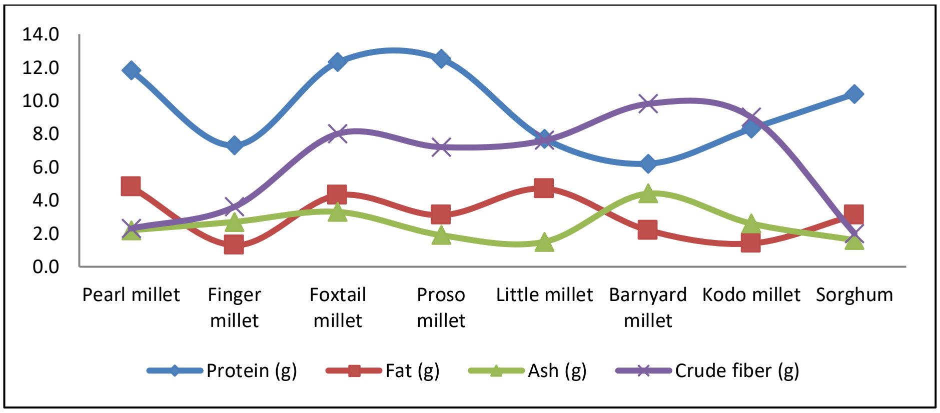

Figure 4.3: Comparison table of nutrient content in different millets per 100 grams of consumption

4.3 Traits Contributing to Climate-Resilience in Millet:

- **Tolerating Climatic Vagaries:** Climate change is generating a rise in the global mean temperature that is lowering agricultural productivity. Furthermore, it has a direct impact on biophysical properties such as animal and plant growth, as well as numerous aspects of food processing and distribution. Regarding present climate change, abiotic stressors offer a considerable risk for plant growth and development, resulting in a yield drop of more than 50% for a popular cereal crop [24].
- **Marginal Cultivation:** Millets are typically grown on marginal lands because of their natural ability to live in such environments and their resistance to abiotic stresses like drought, salinity, and heat. These fields also experience unpredictable and erratic rainfall patterns.
- **Food Security:** Millets offer food, nourishment, fodder, and livelihood security. They also have enormous promise in the fight against poverty and climate change.
- **Low Carbon Footprint:** Millets have a lower carbon footprint over wheat and rice crop, which have carbon dioxide equivalents of 3.9t and 3.4t per hectare, respectively. This contributes to mitigating the effects of climate change.
- **Ephemeral in Nature:** Millets short or limited life-cycle helps them avoid stress because it takes them 6-10 weeks to finish their life-cycle, but rice [25] and wheat [26] take up to 20-24 weeks.
- **Physiological Characteristics:** Because of RUBISCO's strong affinity for CO_2, the C4 mechanism increases CO_2 concentration surrounding the bundle sheath, suppressing photorespiration (about 80%) depending on temperature.
- **C4 Crop:** Millets are a C4 crop that have enhanced photosynthetic rates in warm climates and rapid water and nitrogen use efficiencies that are 1.5 to 4 times higher than those of C3 plants [27].
- **Additional Benefit:** Millets receive additional benefits from C4 photosynthesis in addition to WUE and NUE, such as greater ecological adaptation to hotter temperatures, more variable biomass allocation patterns, and lower hydraulic conductivity per unit of leaf area.

These characteristics of millets make these next-generation cereals with the potential for study into the qualities of climate-resilient plants and for using the knowledge gained to improve major grains.

4.3.1 Resilience of Millets to Various Climate Induced Stresses:

A. Resilience of Millets to Drought Stress Under Changing Climate:

Water shortage is an issue in the majority of semiarid and arid territories of developing nations, which has an impact on the kind and productivity of crops cultivated there. Research including *Panicum miliaceum*, *Setaria glauca*, *Panicum sumatrense*, and *Setaria italic* found substantial productivity loss when exposed to drought stress before flowering [28]. Two landraces of finger millet that had been subjected to drought showed 100% yield loss four weeks after sowing [29]. Due to terminal drought, which is occurred throughout blooming until maturity, a yield loss of almost 60% was noted. For pearl millet, the drought-related yield loss was around 51% [30].

In areas prone to drought, plants use a variety of abiotic stress tolerance mechanisms. A study of four fundamental millet adaptation mechanisms in places suffering from drought was published recently. These defence strategies include (i) **drought avoidance**, that is plant's capacity to maintain water balance amid stress preventing tissues water deficiency, (ii) **drought tolerance**, referring to a plant's capacity to yield biomass despite having less water available, (iii) **drought escape**, is a circumstance in which plants reach maturity prior to experiencing drought stress and (iv) **drought recovery**, which describes that the plant produces a less amount of yield while recovering from the impacts of intermediate drought once the water is available.

Millets' drought adaptations include changes in osmotic adjustment, stomatal opening, and cell membrane stability. One of these is an osmotic adjustment, which allows foliage to regulate leaf turgor pressure sometimes during severe drought by recapturing or absorbing moisture from even dry soils. The metabolic foundation of osmotic adjustment involves both inorganic and organic components, with proline build-up in moisture stress associated with improved drought tolerance.

Stomatal conductance is a measurement of how quickly CO_2 diffuses into the leaf or how quickly water vapour diffuses from the spaces behind the stomata. Under severe drought conditions, the plant closes the stomata to reduce transpiration, which also reduces stomatal conductance. Another way of coping with drought stress is increased root elongation. For instance, when subjected to drought, legumes like *Vigna unguiculata*, *Glycine max*, and *Arachis hypogaea* expand the length of their roots, allowing them to absorb water at a deeper level of the soil.

In reaction to drought stress, this crop will enable its foliage to roll and fold to reduce transpiration and the area covered by the leaves. Drought-induced at 21 days after germination caused leaf folding in a pearl millet genotype (IP 8210) recognized because of its drought resilience. However, it recovered by re-watering 12 days later [31].

Early flowering is an essential drought-escape strategy in crops, and rapid blooming following a short vegetative phase in wheat is a reaction to imminent terminal stress conditions [32, 33]. The presence of a waxy cuticle and asynchronous tiller development (found in pearl millet) are some other drought-resistant mechanisms.

B. Resilience of Millets to Heat Stress Under Changing Climate:

Even though the majority of millet species are heat-tolerant, heat causes several physiological and biochemical changes. The most vulnerable biological functions to heat stress are photosynthesis and respiration, which have a significant impact on crop yield. Up to a certain threshold (32 °C for cotton, 30 °C for soybeans, and 29 °C for maize), crop output rises with rising temperatures; but, beyond that threshold, even a small rise in temperature does indeed have a major negative influence on plant development and, ultimately, yield.

High-temperature stress hinders photosystem II activity, decreases electron transport, and increases ROS build-up. Moreover, it also desiccates the reproductive parts, which may cause plant infertility, seed abortion, a decrease in the number of seeds, and a shorter grain filling duration. Incompletely reduced oxygen species, such as the extensively researched singlet oxygen ($^1O_2$), superoxide anions (O_2), hydrogen peroxide (H_2O_2), and hydroxyl radicals (OH), are collectively referred to as "ROS". ROS have a quick half-life and significant chemical activity.

They have the capacity to cause protein denaturation and lipid peroxidation, ultimately resulting in cell death. Also, they play a major role in the induction of programmed cell death by acting as signaling molecules that change the characteristics of proteins by creating covalent bonds.

Resistant plants generate antioxidants such as copper-zinc superoxide dismutase's (SOD), ascorbate peroxidases (APX), catalases (CAT), thylakoidal ascorbate peroxidase (tAPX), and glutathione peroxidase (GPX), to detoxify oxidative stress either by scavenging ROS superoxide or by activating a variety of detoxifying and protective proteins, preventing oxidative damage in plants under stress. Transcription factors, signaling molecules, heat-shock proteins, ion transporters, and the accumulation of osmoprotectants are some of the other mechanisms of tolerance [34].

C. Resilience of Millets to Water Logging Stress Under Changing Climate:

In high-precipitation regions, water logging stress is the primary cause of poor production [35]. Under conditions of water logging, water seeps into the soil pores, causing toxic chemicals to build up and preventing gas diffusion.

This ultimately has an impact on photosynthesis, stomatal conductance, and roots. Water logging primarily affects crops such as wheat and maize due to the high water-holding capacity of black clay soil [36]. Water logging treatment that has been applied from 2 weeks after planting to harvesting time resulted in corn production losses of approximately 18% for wild millet and 16% for proso millet [37].

Plants have a variety of defences against the stress of water logging, which is brought on by hypoxia (low oxygen levels) or anoxia (total absence of oxygen). It has been shown that finger millet (*Eleusine coracana*) also engages in anaerobic respiration as a response to low oxygen levels [38].

Although anaerobic metabolism is less effective than aerobic metabolism, ATP generated during fermentation temporarily sustains the cell. Water logging tolerant plants such as finger millet and rice demonstrate alterations in carbohydrate metabolism because this method demands higher sugar than aerobic metabolism.

Tolerant plants develop spongy tissue with air holes, called aerenchyma, during water logging stress, allowing gases to flow from stems to roots. These spaces can form either with or without cell death (schizogenous or lysigenous).

According to studies, aerenchyma (lysigenous) develops in the stressed sunflower (*Helianthus annuus*) within two days of the start of the stress. The growth of adventitious roots is another tactic used by plants resistant to water logging. In sorghum (*Sorghum bicolor*) and finger millet, adventitious roots have been seen to develop [39]. Certain crops, such as mung beans (*Vigna radiata*), have been observed to avoid logging due to their quick growth. While water logging tolerant crops, such as tef, react to water logging stress via raising the efficiency of nitrogen reductase inside the shoots, water logging tolerant plants also have enough solubilised sugar.

D. Resilience of Millets to Lodging Stress Under Changing Climate:

A typical issue with millet crops is lodging, which is the persistent bending of the stem from an upright posture. Many investigations have shown that lodging stress reduces tef and foxtail millet yield of crops. Compared to other cereal crops, millets are highly resilient to abiotic stresses, such as lodging.

However, new practices must be introduced, or existing ones must be modified in order for millets to benefit from application of suitable fertilizer to maximize crop yields. Simply limiting plant height through genetic alteration or exogenous chemical methods is a common approach for managing lodging stress [40]. Changes in the date of seeding, tilling techniques, and increasing intra-row space or lowering the number of plants in a row are further crop management techniques that might lessen lodging.

Also, it has been demonstrated that adding silicon amendments increases the output [41, 42]. According to reports, rice with a silica treatment had stronger stems due to increased silica deposition in the shoot, thicker or stronger culm walls, and improved stem stability [43, 44]. Several strategies have been used in millet crops to lessen or eliminate lodging stress and increase production. For instance, it has been demonstrated that applying Paclobutrazol to tef and finger millet reduces the height of the plants and lodging stress [45]. According to [46], gamma radiation or ethyl methane sulfonate (EMS) might induce nonlodging mutants in the kodo millet CO3 variety. Also, they created mutants (known as second mutants or M2) that had increased lodging tolerance due to culm thickness and photosynthetic efficiency (PhE).

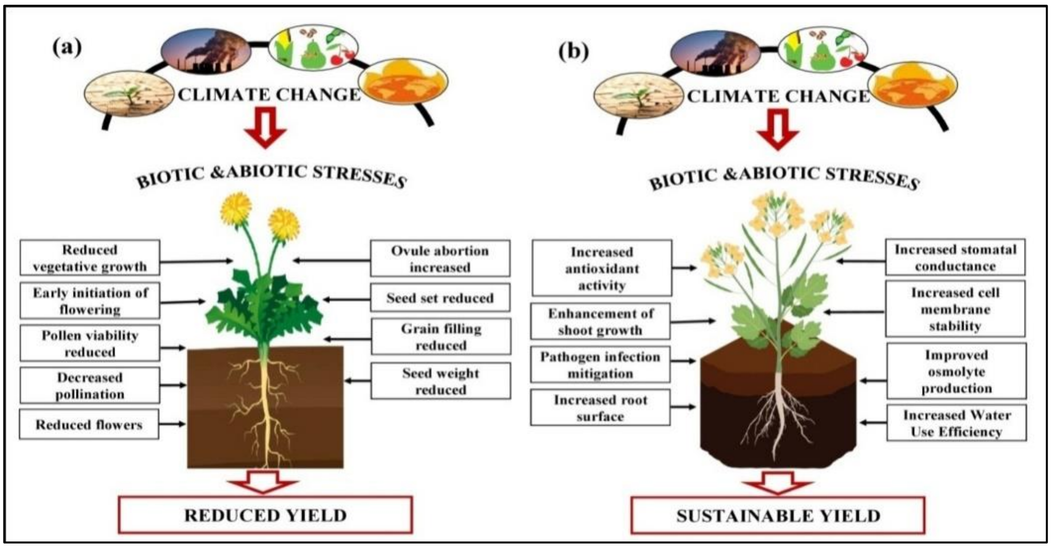

Figure 4.4: (a) Negative impact of various stresses due to climate change on the physiological processes of plant leading to reduce yield (b) Positive impact of millets that mitigate the negative impact of various stresses of global warming and climate change on plants physiological processes contributing to sustainable yield

4.4 Ways to Improve the Climate Resilience in Millet Crops:

A. Application of Plant Growth Promoting Rhizobacteria for Inducing Stress Tolerance in Millets:

These are the bacteria living in the rhizosphere of the soil, which can also be used to alleviate the biotic and abiotic stresses in crops due to climate change by enhancing the plant's performance. These organisms improve plant growth through the biosynthesis of plant growth regulators such as indole acetic acids (IAA) and gibberellic acid (GA3). The IAA synthesizing rhizobacteria results in enhanced root growth through the formation of lateral roots and root hairs. The ability of bacteria to produce hormones and to stimulate the production of endogenous hormones both considerably improve resistance. Moreover, PGPRs were reported to activate plant defence mechanisms and manufacture other growth regulators, including salicylic acid and jasmonic acid. It was also shown to assist plants with nutrient uptake from the soil under stressful circumstances. The presence of PGPRs improves the integrity of plant cell membranes by activating the antioxidant defence mechanism, increasing plants' drought-resistant ability.

B. Application of CRISPR/Cas9 to Improve Stress Tolerance in Millets:

The use of Genome-editing techniques has grown in recent times. One such technique is the utilization of the CRISPR/Cas9 genome-editing technique, which involves the identification of a candidate gene from a selected crop. A guide RNA is thereafter created with this gene of interest and inserted in a binary vector.

A binary vector also contains a Cas9 protein, an enzyme from bacteria. The next step is Agrobacterium-mediated transformation for trait enhancement using these gRNAs and Cas9 expression cassettes. The first millet crop sequenced was the foxtail millet plant [47].

C. Application of Seed Priming to Improve Stress Tolerance in Millets:

Seed priming is the process of treating seeds with natural and synthetic substances prior to germination in order to induce a certain physiological condition in plants. Without significantly reducing crop growth, it shields plants from infections and abiotic stressors. Seed priming has been reported to increase plant resilience to biotic stresses such as weeds, insects, pests, and diseases [48]. When compared to unprimed seeds, *Agropyron elongatum* seeds primed with gibberellin (GA) and abscisic acid (ABA) showed enhanced CAT and SOD activity which are known to impart drought resistance [49].

4.5 Biofortification of Millets Under Changing Climate:

Increasing the micronutrient content of staple crops by biological methods like plant breeding and genetic engineering is known as "biofortification." The biofortification of millets is an essential aspect of the changing climate. Climate change and global warming have caused serious ill effects on humans. The loss of nutrients from the soil and the accumulation of a harmful substance in the crop grains are visible through various deadly diseases in humans and animals. Thus, biofortification of millets for improvement of nutrient content in millets can increase the nutrient content of millet crops, which could alleviate malnutrition in people. Some of the biofortified varieties recently developed are:

Pearl millet- ICMH 1202, HHB 299, ICMH 1301, RHB 233, RHB 234

Sorghum ICSR- 14001 (Prabhani Shakti)

Finger millet- CFMV 1 (Indravathi), CFMV 2, Vegavathi

Little millet- CLMV-1, Sreeneelima

4.6 Conclusion:

The evergreen millet crops are the most promising crops under global warming and climate change. This was witnessed worldwide by the recognition of the year 2023 as the international year of millets. Their various morphological and physiological features, along with nutritional characteristics, are the characteristics that confer their climate resilience. These climate-resilient features enable them to flourish and overcome multiple biotic and abiotic stresses. However, despite having these enormous features, the ever-increasing climatic vagaries remain a threat to millet production. Thus, by applying newly emerging technologies such as PGPRs, CRISPR, and biofortified varieties, the climate resilience of millets could be further improved.

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