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Review

Mechanisms and Approaches for Salt Tolerance in Turmeric: A Breeding Perspective

Arpitha Shankar Bandi [1], Prashant Kaushik [2, 3, *]

1. Acharya N G Ranga Agricultural University, Tirupati, Andhra Pradesh, India; E-Mail: arpithashnkr94@gmail.com
2. Kikugawa Research Station, Yokohama Ueki, 2265, Kamo, Kikugawa City, Shizuoka 439-0031, 6 Japan; E-Mail: prakau@alumni.upv.es
3. Instituto de Conservación y Mejora de la Agrodiversidad Valenciana, Universitat Politècnica deValència, Valencia, Spain

* **Correspondence:** Prashant Kaushik; E-Mail: prakau@alumni.upv.es

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Abstract

India is home to several medicinal herbs including turmeric. Turmeric is one of the major produces of India, primarily due to its unique and valuable medicinal and therapeutic properties. However, the growth and yield of turmeric are greatly affected by salt stress in certain parts of the country, especially those near water bodies where significant yield losses have been reported. To mitigate these losses caused by salt stress, certain plant breeding methods, transgenic approaches, and candidate genes along with ion compartmentation have been implemented so that the growth, yields, development of the crops, rhizome size, essential oil content, total polyphenols, and curcumin content are maintained by protecting the crop from wilting and death. Several strategies, along with a proper understanding of the system biology of turmeric, are being studied carefully to identify the stress-tolerant pathways to enhance the adaptability of plants to salt stress or escape the associated effects in severe cases. These strategies will make the turmeric plants more valuable as well as beneficial to humans.

Keywords
Turmeric; salt stress; plant breeding methods; candidate genes; transgenic approaches; ion compartmentation; curcumin content

1. Introduction

Natural medicines involved in Ayurveda have been gaining increasing importance in recent years because of their several health benefits [1]. Ayurveda can be used to treat several health problems; in addition, several of the by-products are highly valuable in other fields. The most commonly used herb or spice in Ayurveda is turmeric, which has received the greatest attention. The rhizome and powder of this herb have been recognized due to their several unique properties [2]. The powder of this plant is used to treat certain health problems, as a colorant and spice powder, and for beauty purposes. Fresh rhizomes can be used for cooking, and dried rhizomes are converted to powder and oil. This herb is known as Indian saffron due to its high curcumin content and vibrant yellow color. In addition, it is known as the Country, the cousin of ginger [2-4].

Turmeric is a herbaceous, rhizomatous herb with tuberous roots and leaves that extend upward from small stems arising from the roots [5]. This plant has unique horizontal rhizome developmental patterns, which contain scales and finger rhizomes attached to the other major rhizomes. Its cultivation, growth, and developmental patterns are similar to those of the ginger plant [6]. Both these plants belong to the same family, i.e., Zingiberaceae. India is the largest producer of turmeric, along with ginger. In addition, these plants occupy important roles in India due to their medicinal properties [7]. India produces more than 80% of the turmeric worldwide, followed by China (around 9%), Myanmar, Nigeria, and Bangladesh. These countries are known to produce high-quality turmeric with higher quantities of essential oils and curcumin contents [8].

The maximum turmeric consumption was recorded in the USA in 2020, followed by UAE, India, Iran, Japan, and South Africa [9]. The USA is the world’s largest importer of turmeric, contributing around 50 million dollars. In contrast, India is known to be the largest exporter of turmeric, which could account for 250 million dollars. Furthermore, certain countries, such as Myanmar and Netherlands compete with India to export turmeric [10, 11].

In general, turmeric is an annual plant that takes 9 to 12 months to complete its growth and maturity of the rhizomes. The plant is cultivated between January and April, which is known to be late spring or early summer—highly suitable for the growth of plants [12]. In general, these plants include medium-duration and late-duration varieties. In medium-duration varieties, the time taken for completion of the crop is around 7 to 9 months, whereas it is about 11 to 12 months in late duration varieties. The late duration varieties are allowed to grow to increase the plants' curcumin content [13, 14].

Turmeric grows well in clay loamy soils, which need to be well-drained and neatly maintained with a pH range between 5 and 7 with good organic matter content [15-17]. This plant requires 2,000 kg of soil for sowing in a one-hectare land area. Simultaneously, the output of one hectare would be around 7 to 10 tons, making Indian soil conditions very beneficial for the growth and development of the plants. The yields of these plants depend on several factors, such as biotic and abiotic stresses, of which, salinity is highly problematic and known to highly reduce the yields. In general, turmeric grows well under the maximum temperature conditions; however, it is highly sensitive to high temperatures [18-20]. The quality of turmeric primarily depends on its curcumin content, which is the most important phenolic compound in turmeric [21].

Along with other volatile compounds and oils, curcumin plays a significant role in treating several diseases and other ailments [11]. For instance, curcumin is known to protect heart health and bone density, fight against certain cancers, and has several other beneficial properties [22]. In addition, curcumin in turmeric is a potent anti-inflammatory agent and a powerful antioxidant that also assists in reducing depression and other problems such as arthritis. In general, 1.53 mg of curcumin is acceptable for an adult for daily intake to maintain a healthy life [23].

The quality or value of the turmeric largely depends on its rhizome size, the number of rhizomes, curcumin content, volatile oils, and total phenolic compounds All these characteristics are considered to count a variety as having superior quality. However, in recent years, the quality and the quantity of turmeric have gradually reduced, largely due to increasing soil saline conditions [24]. Several abiotic stresses are known to affect the crops in several ways. Out of all stresses, salinity stress is known to create several problems in the production and the productivity of the turmeric crop, leading to yield losses and sometimes the death of the plants [25].

Several salt stress mechanisms, approaches, plant breeding methods, transgenic approaches, and identification of salt responsive genes and their response mechanisms have been implemented to mitigate the losses caused by stress and reduce plant yield loss and death [26]. Moreover, the study of certain biochemical compounds beneficial for the growth of plants and phytochemical compounds such as curcumin and other phenolics could be maintained so that it would be helpful and valuable for consumption [27].

In this review, we primarily focused on understanding several mechanisms and breeding programs used for reducing the harmful effects caused by high salt conditions in the soil, which affect the growth, production, and productivity of the turmeric plant by reducing its valuable medicinal therapeutic properties [28]. All these mechanisms were studied in detail, and methodologies were employed to reduce the losses caused by the salinity stress [29].

2. Salinity Responsive Mechanism in Turmeric

Similar to turmeric, several other crops are affected by severe salt conditions in the soils, which the plants absorb. For example, ginger that belongs to the same turmeric family is also significantly affected due to saline conditions [30]. Salinity, significant abiotic stress, affects the crops in several ways concerning yields and sometimes causing the death of plants. The production rate, nitrogen uptake, growth of plants, and reproduction are affected due to yield losses in turmeric due to salinity stress [31]. Sometimes certain salts, such as chlorides that cause high salt conditions in soils, lead to the death of the plants. Accumulation of increased concentrations of salts causes toxicity in plants [32].

The turmeric plants are exposed to salinity conditions due to improper soil maintenance and highly saline areas near water bodies. Generally, in certain parts of India, such as Gujarat, Rajasthan, Kerala, and Karnataka, soils are highly saline; in such places, the monstrance of plant productivity and growth is a problem due to unfavorable soil conditions. Under such conditions, plants develop specific characteristics, including certain physiological and biochemical changes, to tolerate salinity [33].

Under saline conditions, when cellular homeostasis is disturbed, plants undergo certain changes such as disruption of membranes, degradation of proteins, and inactivation of certain enzymes occur. Later specific responsive genes get activated, and their expression results in certain enhanced biological functions. The synthesis of certain proteins occurs immediately. Enzymes are activated, allowing normal functions of the plants to be carried out without causing considerable damage to the yield [34]. The reactivation of certain vital enzymes and proteins occurs after the gene expression, which internally protects the plants from the harmful effects caused by the salts in the soils absorbed by plants [35].

In certain turmeric cultivars that are susceptible to salinity, the damage observed is largely attributed to a lack of expression of salinity-tolerant genes. In such cultivars, the protein synthesis and enzyme activation are halted, several cellular functions are arrested, and various physiological cycles are affected. Specific cellular mechanisms and cell functions are inhibited, leading to the death of plants [36]. Most importantly, plants susceptible to salinity exhibit significant symptoms such as leaf drying, yellowing, stunted growth, improper root and shoot development, improper rhizome formation, thinner leaves, and drooping of plants [37].

Turmeric plants have several responsive mechanisms against salinity. Plant breeding methods such as selecting suitable cultivars and molecular breeding techniques such as gene alterations and expression of certain salt stress-responsive genes are being used to enhance or maintain the yields of the plants and reduce the death of plants to a high extent [38, 39].

3. Restricting Initial Entry of Salts to Roots

Generally, different salts are available in soils that plants absorb in different concentrations. Salts such as $CaCl_2$, NaCl, KCl, and magnesium sulfate salts are primarily available in saline soils at different concentrations [40]. Such soils with mixed salts in various concentrations are saline soils and are of three different types: primary soils that are naturally available in the soils, secondary soils which are present in dry areas where the concentrations of salts largely remain the same, and tertiary soils containing irrigation salts that enter into the soils via irrigation [41]. Such soils are highly effective in causing problems in plant soil absorption, leading to several physiological changes. Morphological, biochemical, and molecular changes in the plants sometimes are beneficial and sometimes lead to plants' death [42].

Water and mineral salts enter the plants through different methods of active transportation, diffusion and osmosis, where water and salts enter into the plant tissues through the xylem from where all salts and water get distributed throughout the plant system. The only mode of entry of salts into the plants is through the plant root system, especially the root hairs that are thin, slender, small, single membraned, and have a large surface area for absorption. The root hairs allow the entry of salts, present in water molecules, into the plants from soils effortlessly. The underground root system plays a significant role in the entry of the salts into the plants [43]. Usually, the water molecules enter the soil through osmosis. In contrast, mineral salts gain entrance into plants by diffusion and active transportation through ion-gated channels and other modes of transport between the root cells and the soil. Thus, several salts enter the plants from saline soils and water;

however, this entry should be restricted properly to avoid the losses caused by high salt concentrations in plants [44].

First, the salt concentration in the soils should be reduced, following which the entry of salts can be restricted. These salts are to be properly restricted by following careful measures to avoid yield losses in the plants as an initial step, leaching should be performed to reduce the salt concentration in soils. In this, the outer saline layer of dirt can be eliminated easily using low-saline waters that are either treated or naturally available. This layer, which is removed, also assists in removing the maximum salt content from soils. Immediately after leaching of soils, tillage should be avoided as it forces the unwanted salts from deep root levels to the surface level of the soils. In addition, establishing a suitable cover crop correctly significantly avoids soil erosion caused by different factors. All these methods could reduce the concentration of the salts in soils; however, restricting the entry of salts into the plants should be avoided This is the most important step, which is attained by following proper agronomic practices and reducing the use of fertilizers and chemicals [45].

Plants can avoid the intake of salts from soils in different ways, for example, the change in the irrigation methods would reduce the entry of salts into the plants, whereas the drip irrigation system can provide several benefits of protecting plants from salinity problems by always maintaining the soil moisture and leaching of salts toward the wetted edges near the plant surface. This is a straightforward and important mechanism through which the salinity of the plants can be significantly reduced to a high extent [46]. The infiltration mechanism of plant roots has also been known to reduce the entry of salts into the plants. This mechanism is purely maintained by the plant. Apart from these mechanisms, highly salt-tolerant varieties are known to provide the maximum benefits compared to other mechanisms by reducing the yield losses, although the plant is exposed to severe salinity stress. In addition, several breeding programs such as mixed cropping, early sowing varieties, and other plant breeding programs have been to reduce the losses caused by salinity stress [47].

Therefore, the restriction of the entry of salts into plants is highly necessary, similar to the reduction of salt concentration in soils, to avoid the losses caused by salinity. It is significant abiotic stress that causes severe yield losses in plants and sometimes the death of plants [48]. Roots are a major area of effect because gases such as oxygen and carbon dioxide enter through leaves, whereas mineral salts and water are absorbed through roots [49].

4. Intracellular Compartmentation of Salts

Along with nutrients and water, plants absorb salts from soils [50]. The absorbed salts get accumulated in plants' cells, leading to increased plant sensitivity and death. In the case of tolerant cultivars, these salts tend to form compartments or get separated in different organelles, mostly vacuoles, and are broken down through phagocytosis. This mechanism is an adaptive stress mechanism, especially in salt-tolerant cultivars [51].

The salts were broken or separated into different ions such as Na and Cl separately and Mg and Cl separately in different cell organelles in the vacuoles [52]. This compartmentation of ions is primarily accumulated in the vacuoles, which are easily broken down through phagocytosis. The pieces of this organelle are digested by cells or released outside in the form of cell debris [53]. Salt-tolerant cultivars adopt this mechanism of ion compartmentation to get rid of excess salts entering the plants. This is an excellent mechanism where plants can remove excess salts to stop the maximum damage [54]. In this way, both salts and unwanted cell substitutes are removed.

Different ions are known to be separated inside vacuoles in large proportions by filling the entire vacuole so that the vacuole would be ready for phagocytosis and released outside the cell as debris. For example, in the case of NaCl, Na ions and Cl ions are separated and accumulated inside the vacuoles (Figure 1) to be released as cell debris.

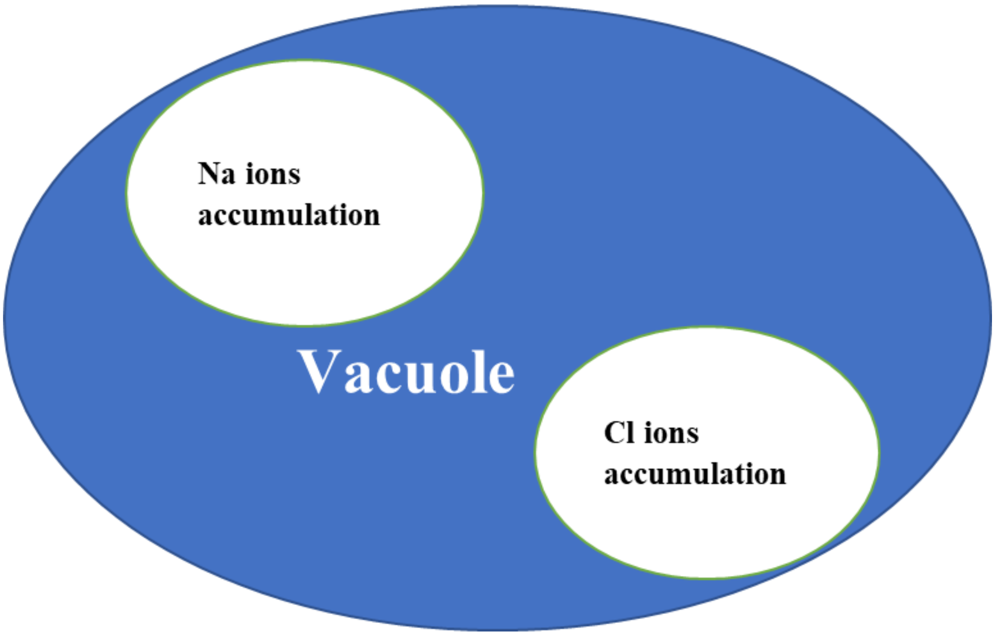

Figure 1 Ion compartmentation in a vacuole.

This is achieved by regular watering of plants with clean water having fewer salts so that the exchange of ions through osmosis occurs efficiently. Thus, the ion compartmentation adapted by salt stress-tolerant cultivars is an excellent mechanism where the yield losses can be significantly reduced. The plants continue to grow as usual without damaging the developing rhizomes and their curcumin content [55].

5. Approaches to Improve Salt Tolerance in Turmeric

Several methods and mechanisms are being used through which the plants can handle the salinity and yield losses, several drying symptoms, and the death of the plants can be reduced. Thus, plants can provide the maximum yields with several beneficial compounds, especially in the case of turmeric, which is a medicinal plant having several health benefits and anti-cancer properties [56, 57]. The primary compound of turmeric is curcumin which is majorly affected by salt stress. Under salt stress, the levels of this compound are highly reduced and the medicinal properties are lost. Conserving these properties and the curcumin content and maintaining proper yields are crucial in turmeric under saline soils [58, 59].

6. Plant Breeding

Several plant breeding methods have been forward to reduce the yield losses in turmeric under salt stress conditions. The primary aim of these breeding programs is to maintain proper productivity and yield in turmeric plants under unfavorable conditions [60].

The objectives involved in plant breeding programs are fundamental to achieving proper yields in any plant. These objectives are fulfilled only under unfavorable conditions. Even under adverse conditions, a certain mechanism is adapted to complete all breeding objectives (Figure 2) so that proper yields and nutritional qualities are maintained.

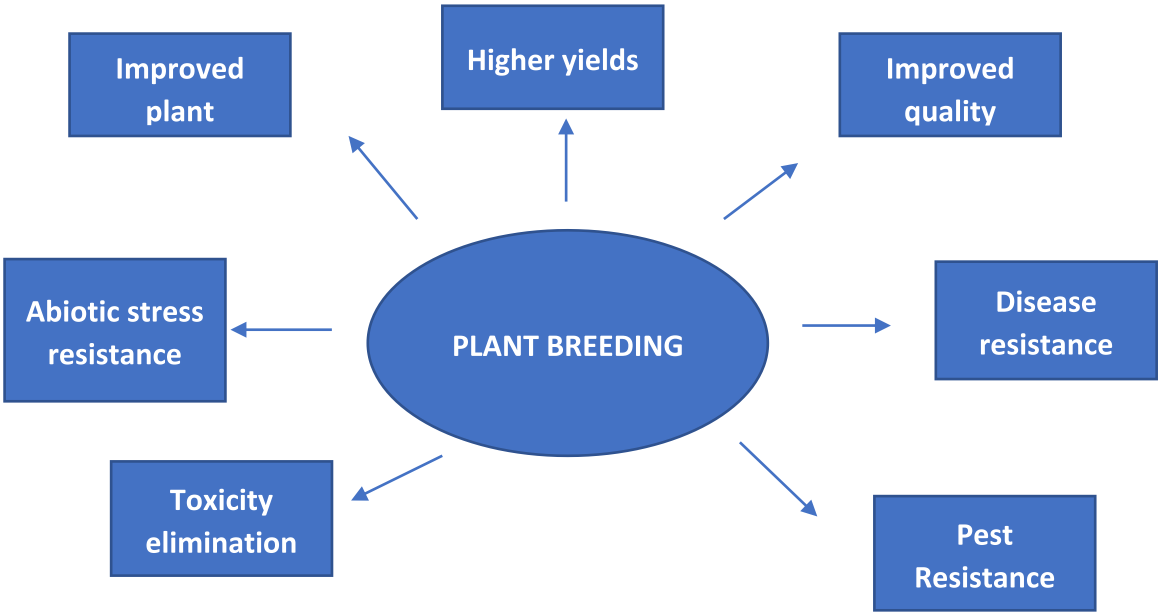

Figure 2 The main objectives of turmeric breeding programs.

The first objective of plant breeding for salinity stress is to avoid the growth of plants under saline soils. This can be achieved by growing turmeric plants having suitable soil conditions by previously testing the soil salt content. The maximum yield losses can be avoided if plants are grown under the right soil types, i.e., with low saline content [61].

Therefore, avoiding sowing crops in already saline soils is the best plant breeding method to reduce the yield losses by salinity [62-64]. The selection of highly tolerant cultivars to salt stress is important along with the early growing varieties that can escape the soil salinity in peak growth stages [65]. These cultivars can be tolerant to salinity up to a certain level, where the yield losses can be maintained without leading to the death of plants. The selection or identification of suitable salt-tolerant cultivars is achieved by the following specific plant breeding methods: Back cross, progeny, and pure line selection. Early growing varieties of turmeric can also be selected to avoid the intense salinity problems during peak growth stages such as the vegetative stage, reproductive stage, and yielding stages. Therefore, plant breeding programs or methods for salinity tolerance include proper soil management and maintenance practices.

7. Breeding Strategies for Salinity Stress in Turmeric

Several breeding techniques have been developed to reduce the salinity stress in turmeric, especially yield losses and severe symptoms that lead to plants' death [66]. Moreover, several investigations have studied the effect of salinity stress in other crop plants along with turmeric.

Similar to other techniques such as molecular markers, mapping, and genetic inheritance, breeding techniques promote salinity tolerance in plants and are affected by genetic inheritance, environmental factors, and the diversity of the species [67].

7.1 Mutational Breeding

Mutational breeding is a breeding technique in which the plant materials used for cultivation are exposed to a certain range of chemicals, radiations, enzymes, etc., to create mutants with desirable characteristics that can be used to breed with other cultivars [68]. These mutagenic plants were identified through screening initially and the type of mutant was confirmed. After these mutants were introduced, the cultivars were grown separately under multi-location trails, following which they were evaluated and released as a new variety [69]. The addition of ethyl methanesulfonate (EMS) increased the salinity tolerance in the treated cultivars compared to normal cultivars. In addition, a significant reduction in the symptoms caused by salinity stress in the cultivars treated with EMS was observed. Therefore, the use of EMS in turmeric could result in salinity tolerance similar to other crops such as rice, barley, and wheat [70].

7.2 Exploitation of Wild Relatives

Different breeding methods are involved in promoting abiotic stress tolerance and protecting plants from severe effects caused by salinity stress. Certain wild relatives of crop plants are known to contain genes responsible for salinity stress tolerance and can control the stress effects in plants [71]. This can be attained through interspecific hybridization between wild relatives and normal plants. Especially in turmeric, the crosses between wild relatives and normal crop plants can result in salinity tolerance to a high extent. For example, a cross between *Curcuma aromatic* (wild relative) and *Curcuma longa* (normal cultivated plant) would probably increase the tolerance toward salt stress as compared to plants that have not been crossed [72, 73].

7.3 Double-Haploid

The production of double haploids has gained considerable importance due to their ease and significance in the present era. This method includes the production of haploid plants followed by chromosomal doubling and their separation depending on the species [74]. This method helps in crop improvement due to its short breeding cycle, homozygosity, recessive allele expressions, etc. In this method, artificial chromosome doubling is performed through colchicine treatment or genome doubling by endomitosis [75] and can be used in turmeric for producing cultivars that are salt-tolerant [76].

7.4 Marker-assisted Selection

This is a unique and indirect process of selection in which the marker is selected based on the trait of interest at the genome level rather than the phenotypic importance [77]. These molecular markers are always associated with genomics and linkage maps. The selection of a perfect marker with the trait of interest or any marker associated with QTL would increase the chances of developing cultivars with required traits. This technique has been combined with molecular biology techniques such as SNPs, AFLPs, In-DELs, and SSRs and next-generation sequencing techniques.

Previously, marker-assisted breeding was time-consuming and labor-intensive [78]. However, the advancement of biotechnology has made it easier to use specific markers required for the traits. MAB promotes the selection of desirable parents with traits of interest and allows select offspring at an early stage to promote tolerance against different stresses. Several studies have reported achieving salinity stress tolerance in rice, barley, and several other crops through MAB. In addition, drought stress tolerance was achieved in chickpea and rice using MAB. Therefore, this method is highly accurate and rapid in producing offspring with desired traits by pyramiding desired QTLs. This method can also improve the genomic nature of turmeric cultivars by proper QTL mapping through which tolerance against salinity can be achieved [79].

8. System Biology

System biology is a multidisciplinary approach that deals with bioinformatics; it is a computational analysis that assists in modeling complex biological systems [80]. System biology uses an *in silico* approach to understand and identify the models of DNA, RNA, and proteins that are interrelated or belong to the same species [81]. These models can also be compared with other living biological models of different species, thus, allowing us to study the genetic and biological interventions in the organisms concerning genes and proteins. It is a mechanism in which a group of organs performs a similar function, where these organs work together against any particular stress (biotic or abiotic). System biology checks whether the organs can function together by coordinating them through signal transduction [82].

System biology can be well understood by studying its goals where it deals with [83],

- Proper understanding of biology
- Careful study of biological mechanisms
- A clear understanding of the interactions between cells, genetic material, and proteins.
- Understanding different properties of cells
- Helps interrogate different biological systems on a large scale.

Although systems biology is a new approach with high use in agriculture, medicine, and other areas, the understanding of its concepts and the interpretation of results has been a problem. Nevertheless, it paves the way for easy identification of the complex genomes and areas of high risk in the entire genome [84, 85].

In the case of turmeric, under salt stress conditions, the maintenance of the crops is the most crucial step. In addition, avoiding crop growth on saline soils is a significant step toward reducing the effects of salinity. Because of unpredictable conditions in the agricultural systems and the environmental issues, computer-based knowledge is being used for proper understanding of the stress and following necessary steps to protect the crop and minimize the yield losses [86]. This system-based biological understanding of a particular crop under particular stress provides us with detailed information. Because systems biology uses bioinformatics, it promotes the development of novel drugs and antibiotics that are highly effective and provides the gene sequences responsive to salinity stress turmeric. The systems biology approaches largely help researchers to construct model networks similar to the original problems associated with plant bodies [87, 88].

9. Transgenic Approaches

Several approaches and methods are available to reduce the losses caused by salt stress in turmeric plants; however, not all approaches are practical and advantageous. Considering these problems, transgenic approaches such as gene identification, tissue culture, genome editing, and rDNA technologies came into existence to nullify these problems [89]. The concept of transgenic crops has gained considerable importance in recent years due to their several benefits. These crops are sometimes not selected for growth or consumption purposes in certain parts of the world due to political issues and a lack of knowledge on transgenic crops [90].

The adjustment of transgenic crops to the outside environment is sometimes problematic and depends on the nature of the crop, area, and adaptability of genes. Several transgenic crops have been developed for insect resistance, disease resistance, herbicide resistance, and several other abiotic stress resistance [91]. Crops such as tomatoes for shelf life, potatoes for yields, and maize against borers have also been developed to minimize losses and promote crop yields [92]. These crops need some time to adjust to the outside environment.

In the case of turmeric, especially under salt stress, several genes are isolated and well expressed under severe salinity conditions so that the growth of plants can be promoted without the death of any plants [93]. Similar genes were known to be responsive in ginger, which belongs to the same family as turmeric. In addition, under severe salt conditions, specific genes are expressed that contribute to curcumin content. These transgenic plants involve single action genes that alter the stress conditions and increase the tolerance toward that particular stress, such as salinity, drought, heat, and cold [94, 95].

In general, the expression of genes contributing to abiotic stress resistance can be categorized into different groups, which include

- Genes for enzymatic and structural functions,
- Unknown protein functions and
- Regulatory proteins

The expression of different genes during high saline conditions is more likely to affect the production of several enzymes, change in structural functions of cell organelles, other protein functions and synthesis, and the action of different regulatory proteins so that the change in all plant functions would promote the growth of plants under severe stress conditions so that the maximum yield losses can be minimized in turmeric plants [96]. Therefore, transgenic turmeric plants against salinity stress is a beautiful method to reduce the yield losses and promote plant growth along with increased rhizome size and curcumin content [97, 98].

10. Candidate Genes Likely to Contribute to Salt Tolerance in Turmeric

Several genes are responsible for promoting tolerance against different stresses in several plants. These genes play a significant role in enhancing the function of other proteins in the plant system so that the growth yields are not affected by stress conditions. However, plants could be protected from severe damage [99]. Candidate genes are similar to the genes of interest or closely associated with that gene. This gene of interest can be associated with salinity tolerance or any other abiotic stress [100].

Several genes in turmeric are known to affect the growth of plants under salt stress conditions, where these genes minimize the losses caused by the stress and promote the growth of crops. This *NHX* gene is present in turmeric and ginger and belongs to the solanaceous family. However, the response of this gene is not high in the Zingiberaceae family but is well responsive in the case of the Solanaceous family [31].

The calcium-dependent protein kinase gene, i.e., *CDPK1*, is also known to be upregulated under salt stress conditions. This gene is known to be expressed in ginger, which belongs to the same family as turmeric. This gene is expressed under high salt conditions during the initial stages of turmeric plant growth. Furthermore, specific other genes such as *MAPK1*, *DCS*, and phytocystatin are known to promote tolerance toward severe salt conditions in turmeric. These genes are upregulated in turmeric plants so that the growth of the plants can be promoted, and the yields can be maintained under severe stress conditions. *MAPK* gene known as mitogen-activated protein kinase gene and DCS gene, i.e., Diketide Co-A synthase are activated under salt stress conditions where these genes are upregulated to reduce the harmful effects caused by salt stress in turmeric [32].

The phytocystatin gene is a novel gene and is upregulated under salt conditions in turmeric. This gene is upregulated even under drought conditions in soybean plants and certain other legumes. Therefore, this particular gene is responsive under salt and drought conditions, promoting the plants' growth even under severe abiotic stress conditions such as salt in turmeric and drought in case of legumes. The role of these genes in plants is highly important as these protect the plants from severe damage and death, leading to proper yields. In the case of turmeric, the growth of the plant, rhizome size, and curcumin content are important parameters considered for a healthy turmeric plant. These parameters are not always achieved, especially under salt stress conditions [33, 34].

Because curcumin is an important phenolic compound in turmeric with several medicinal properties, it has been used to treat several health issues such as arthritis, cancers, and heart diseases. Certain CURS genes, including *CURS1*, *CURS2*, and *CURS3*, are responsive under salt stress conditions where these genes promote the production of curcumin content in turmeric. These genes are known to be highly responsive under drought stress conditions in turmeric by which the responsive nature of genes toward abiotic stresses is well understood. The production of curcumin is promoted to a certain level even under severe stress conditions in turmeric, thereby increasing the plant tolerance, enhancing the yield, and minimizing the losses caused by the salt stress. Therefore, these genes, expressed in turmeric under high salt stress conditions, play an essential role in upregulating the system, thereby making the turmeric plants tolerant to severe salinity stress. The yield losses are greatly minimized [36].

11. Conclusion and Prospects

Compared to other medicinal plants in India, turmeric plays a significant role in providing several health benefits and therapeutic properties, playing major roles in developing immunity in humans and exerting beneficial effects on soil. Curcumin is the major component in turmeric plants with these unique properties. The levels of curcumin content, rhizome size, and total yield of the plants are greatly affected by the soil salinity, making the plants prone to stress, reducing yields, and ultimately inhibiting the death of the plants.

All breeding practices employed for salinity stress aim at producing high-yielding vigorous hybrids or varieties that can grow under severe salt stress conditions. Several theories have been put forward along with techniques that are successful in protecting the plants from saline stress.

However, these techniques are not a complete solution for protecting the plants under salt stress conditions. Therefore, several breeding methods such as double haploid production, MAB, use of wild relatives and mutation breeding, transgenic approaches, and use of various candidate genes have been used to protect the plants against salinity stress conditions. Accordingly, several plant breeding conditions have been developed to reduce the yield losses caused by salt stress where the trigger for the salt stress is appropriately checked and arrested. Therefore, the initial field contamination with salt is nullified by following careful irrigation practices and soil maintenance. Using salt-tolerant cultivars that can be hybrids from different crosses, including wild relatives, is also known to reduce salt stress. Compared to several other methods followed by researchers, the implementation of plant breeding techniques along with the use of advanced molecular biology techniques paves the way for a better understanding of crop nature, improving tolerance against stresses, releasing new varieties, and also resulting in the production of improved offspring.

In addition, transgenic approaches such as different gene transfer methods, recombinant DNA technology, hybridization techniques, tissue culture methods, and genome editing promote the growth of turmeric plants affected by salt stress. The growth-promoting genes may be inserted into the plants to trigger responsible cell functions so that the yield losses can be minimized to a greater extent. Along with transgenic approaches, the expression of candidate genes also plays a significant role in promoting the growth of turmeric plants affected by salinity. Specific essential genes such as *CDPK 1*, *MAPK 1*, *DCS*, *Polyketide III*, and *CURS* genes are known to promote the growth of plants by their upregulation under salt stress conditions. The response of these genes under certain stress conditions in different stages of turmeric crop growth promotes the tolerance in plants toward salinity stress. Therefore, the upregulation of these genes is highly beneficial for the proper protection of the plants. Thus, turmeric is considered a number one medicinal herb; its high sensitivity to salt stress can be coped up using different breeding programs, transgenic approaches, and upregulation of candidate genes.

12. Future Prospects

- Maintaining healthy soil conditions
- Following proper irrigation practices with clean water
- Avoiding sea areas or nearby areas for the cultivation of turmeric plants
- Following proper breeding practices for higher yields
- Selecting salt-tolerant varieties for cultivation
- Developing more cultivars that are adaptable to salt stress
- Modifying genes using different transgenic approaches and cutting-off yield losses
- Identifying and selecting salinity-tolerant genes
- Promoting proper breeding methods suitable for salinity tolerance
- Using wild relatives as a source of new genes for improving plant tolerance through plant breeding.

Author Contributions

P.K. conceived of and designed the project. P.K. supervised the study. A.S.B. and P.K. wrote the paper. P.K. corrected the final draft. Both authors read and approved the final manuscript.

Competing Interests

The authors have declared that no competing interests exist.

References

1. Munekata PE, Pateiro M, Zhang W, Dominguez R, Xing L, Fierro EM, et al. Health benefits, extraction and development of functional foods with curcuminoids. J Funct Foods. 2021; 79: 104392.
2. Al-Obaidi LFH. Effect of adding different concentrations of turmeric powder on the chemical composition, oxidative stability and microbiology of the soft cheese. Plant Arch. 2019; 19: 317-321.
3. Cefalu WT, Berg EG, Saraco M, Petersen MP, Uelmen S, Robinson S. Classification and diagnosis of diabetes: Standards of medical care in diabetes-2019. Diabetes Care. 2019; 42: S13-S28.
4. Arango C, Díaz-Caneja CM, McGorry PD, Rapoport J, Sommer IE, Vorstman JA, et al. Preventive strategies for mental health. Lancet Psychiatry. 2018; 5: 591-604.
5. Asadi S, Gholami MS, Siassi F, Qorbani M, Khamoshian K, Sotoudeh G. Nano curcumin supplementation reduced the severity of diabetic sensorimotor polyneuropathy in patients with type 2 diabetes mellitus: A randomized double-blind placebo-controlled clinical trial. Complement Ther Med. 2019; 43: 253-260.
6. Barber-Chamoux N, Milenkovic D, Verny MA, Habauzit V, Pereira B, Lambert C, et al. Substantial variability across individuals in the vascular and nutrigenomic response to an acute intake of curcumin: A randomized controlled trial. Mol Nutr Food Res. 2018; 62: 1700418.
7. Campbell MS, Ouyang A, Krishnakumar I, Charnigo RJ, Westgate PM, Fleenor BS. Influence of enhanced bioavailable curcumin on obesity-associated cardiovascular disease risk factors and arterial function: A double-blinded, randomized, controlled trial. Nutrition. 2019; 62: 135-139.
8. Dei Cas M, Ghidoni R. Dietary curcumin: Correlation between bioavailability and health potential. Nutrients. 2019; 11: 2147.
9. Prediabetes—Your chance to prevent type 2 diabetes [Internet]. Centers for Disease Control and Prevention; 2021. Available from: https://www.cdc.gov/diabetes/basics/prediabetes.html.
10. Chemat F, Vian MA, Fabiano-Tixier AS, Nutrizio M, Jambrak AR, Munekata PE, et al. A review of sustainable and intensified techniques for extraction of food and natural products. Green Chem. 2020; 22: 2325-2353.
11. Sanidad KZ, Sukamtoh E, Xiao H, McClements DJ, Zhang G. Curcumin: Recent advances in the development of strategies to improve oral bioavailability. Annu Rev Food Sci Technol. 2019; 10: 597-617.
12. Briskey D, Sax A, Mallard A, Rao A. Increased bioavailability of curcumin using a novel dispersion technology system (LipiSperse®). Eur J Nutr. 2019; 58: 2087-2097.
13. Shep D, Khanwelkar C, Gade P, Karad S. Safety and efficacy of curcumin versus diclofenac in knee osteoarthritis: A randomized open-label parallel-arm study. Trials. 2019; 20: 214.
14. Wu J, Lv M, Zhou Y. Efficacy and side effect of curcumin for the treatment of osteoarthritis: A meta-analysis of randomized controlled trials. Pak J Pharm Sci. 2019; 32: 43-52.
15. Jadhao A, Bhuktar A. Genus curcuma L.(Zingiberaceae) from maharashtra state—India. Int J Curr Res Biosci Plant Biol. 2018; 5: 39-48.

16. Li X, Ma S, Yang P, Sun B, Zhang Y, Sun Y, et al. Anticancer effects of curcumin on nude mice bearing lung cancer A549 cell subsets SP and NSP cells. Oncol Lett. 2018; 16: 6756-6762.
17. Li H, Sureda A, Devkota HP, Pittalà V, Barreca D, Silva AS, et al. Curcumin, the golden spice in treating cardiovascular diseases. Biotechnol Adv. 2020; 38: 107343.
18. Macías-Pérez JR, Vázquez-López BJ, Muñoz-Ortega MH, Aldaba-Muruato LR, Martínez-Hernández SL, Sánchez-Alemán E, et al. Curcumin and α/β-adrenergic antagonists cotreatment reverse liver cirrhosis in hamsters: Participation of Nrf-2 and NF-κB. J Immunol Res. 2019; 2019: 3019794.
19. Murthy KC, Monika P, Jayaprakasha G, Patil BS. Nanoencapsulation: An advanced nanotechnological approach to enhance the biological efficacy of curcumin. In: Advances in plant phenolics: From chemistry to human health. ACS Publications; 2018. pp.383-405.
20. Salehi B, Calina D, Docea AO, Koirala N, Aryal S, Lombardo D, et al. Curcumin's nanomedicine formulations for therapeutic application in neurological diseases. J Clin Med. 2020; 9: 430.
21. Salehi B, Prado-Audelo D, María L, Cortés H, Leyva-Gómez G, Stojanović-Radić Z, et al. Therapeutic applications of curcumin nanomedicine formulations in cardiovascular diseases. J Clin Med. 2020; 9: 746.
22. Sri SN, Thiagarajan R, Manikandan R, Arumugam M. Curcumin-based food supplements: Challenges and future prospects. In: Nonvitamin and nonmineral nutritional supplements. Elsevier; 2019. pp.119-128.
23. Subramani PA, Cheeran V, Munuswamy-Ramanujam G, Narala VR. Clinical trials of curcumin, camptothecin, astaxanthin and biochanin. Natural Prod Clin Trials. 2018; 1: 10.2174.
24. Teter B, Morihara T, Lim G, Chu T, Jones M, Zuo X, et al. Curcumin restores innate immune alzheimer's disease risk gene expression to ameliorate alzheimer pathogenesis. Neurobiol Dis. 2019; 127: 432-448.
25. Xu XY, Meng X, Li S, Gan RY, Li Y, Li HB. Bioactivity, health benefits, and related molecular mechanisms of curcumin: Current progress, challenges, and perspectives. Nutrients. 2018; 10: 1553.
26. Yeung AWK, Horbańczuk M, Tzvetkov NT, Mocan A, Carradori S, Maggi F, et al. Curcumin: Total-scale analysis of the scientific literature. Molecules. 2019; 24: 1393.
27. Zhu LN, Mei X, Zhang ZG, Xie Yp, Lang F. Curcumin intervention for cognitive function in different types of people: A systematic review and meta-analysis. Phytother Res. 2019; 33: 524-533.
28. Sharifi-Rad J, Rayess YE, Rizk AA, Sadaka C, Zgheib R, Zam W, et al. Turmeric and its major compound curcumin on health: Bioactive effects and safety profiles for food, pharmaceutical, biotechnological and medicinal applications. Front Pharmacol. 2020; 11: 1021.
29. Thota RN, Dias CB, Abbott KA, Acharya SH, Garg ML. Curcumin alleviates postprandial glycaemic response in healthy subjects: A cross-over, randomized controlled study. Sci Rep. 2018; 8: 1-8.
30. Pellicer J, Leitch IJ. The plant DNA C-values database (release 7.1): An updated online repository of plant genome size data for comparative studies. New Phytol. 2020; 226:301-305.
31. Mohanta TK, Yadav D, Khan AL, Hashem A, Abd Allah EF, Al-Harrasi A. Molecular players of EF-hand containing calcium signaling event in plants. Int J Mol Sci. 2019; 20: 1476.
32. Li M, Hu W, Ren L, Jia C, Liu J, Miao H, et al. Identification, expression, and interaction network analyses of the CDPK gene family reveal their involvement in the development, ripening, and abiotic stress response in banana. Biochem Genet. 2020; 58: 40-62.

33. Tong X, Cao A, Wang F, Chen X, Xie S, Shen H, et al. Calcium-dependent protein kinase genes in glycyrrhiza uralensis appear to be involved in promoting the biosynthesis of glycyrrhizic acid and flavonoids under salt stress. Molecules. 2019; 24: 1837.
34. Chen DH, Liu HP, Li CL. Calcium-dependent protein kinase CPK9 negatively functions in stomatal abscisic acid signaling by regulating ion channel activity in arabidopsis. Plant Mol Biol. 2019; 99: 113-122.
35. Dubrovina A, Kiselev K. The role of calcium-dependent protein kinase genes VaCPK1 and VaCPK26 in the response of vitis amurensis (in vitro) and arabidopsis thaliana (in vivo) to abiotic stresses. Russ J Genet. 2019; 55: 319-329.
36. Ning M, Tang F, Zhang Q, Zhao X, Yang L, Cai W, et al. Effects of penicillium infection on the expression and activity of CDPK2 in postharvest hami melon treated with calcium chloride. Physiol Mol Plant Pathol. 2019; 106: 175-181.
37. Dubrovina A, Aleynova O, Manyakhin A, Kiselev K. The role of calcium-dependent protein kinase genes CPK16, CPK25, CPK30, and CPK32 in stilbene biosynthesis and the stress resistance of grapevine Vitis amurensis rupr. Appl Biochem Microbiol. 2018; 54: 410-417.
38. Wang J, Wang S, Hu K, Yang J, Xin X, Zhou W, et al. The kinase OSCPK4 regulates a buffering mechanism that fine-tunes innate immunity. Plant Physiol. 2018; 176: 1835-1849.
39. Baba AI, Rigó G, Ayaydin F, Rehman AU, Andrási N, Zsigmond L, et al. Functional analysis of the arabidopsis thaliana CDPK-related kinase family: ATCRK1 regulates responses to continuous light. Int J Mol Sci. 2018; 19: 1282.
40. Abedinzadeh M, Etesami H, Alikhani HA. Characterization of rhizosphere and endophytic bacteria from roots of maize (Zea mays L.) plant irrigated with wastewater with biotechnological potential in agriculture. Biotechnol Rep (Amst). 2019; 21: e00305.
41. Acuña JJ, Campos M, de la Luz Mora M, Jaisi DP, Jorquera MA. ACCD-producing rhizobacteria from an andean altiplano native plant (Parastrephia quadrangularis) and their potential to alleviate salt stress in wheat seedlings. Appl Soil Ecol. 2019; 136: 184-190.
42. Albdaiwi RN, Khyami-Horani H, Ayad JY, Alananbeh KM, Al-Sayaydeh R. Isolation and characterization of halotolerant plant growth promoting rhizobacteria from durum wheat (Triticum turgidum subsp. durum) cultivated in saline areas of the dead sea region. Front Microbiol. 2019: 1639.
43. Al-Garni SM, Khan MMA, Bahieldin A. Plant growth-promoting bacteria and silicon fertilizer enhance plant growth and salinity tolerance in coriandrum sativum. J Plant Interact. 2019; 14: 386-396.
44. Ceci A, Pinzari F, Russo F, Maggi O, Persiani AM. Saprotrophic soil fungi to improve phosphorus solubilisation and release: In vitro abilities of several species. Ambio. 2018; 47: 30-40.
45. Chang T, Zhang Y, Xu Hl, Shao X, Xu Q, Li F, et al. Osmotic adjustment and up-regulation expression of stress-responsive genes in tomato induced by soil salinity resulted from nitrate fertilization. Int J Agric Biol Eng. 2018; 11: 126-136.
46. Cuevas J, Daliakopoulos IN, del Moral F, Hueso JJ, Tsanis IK. A review of soil-improving cropping systems for soil salinization. Agronomy. 2019; 9: 295.
47. Egamberdieva D, Wirth S, Bellingrath-Kimura SD, Mishra J, Arora NK. Salt-tolerant plant growth promoting rhizobacteria for enhancing crop productivity of saline soils. Front Microbiol. 2019: 2791.

48. Gururaja Rao G, Kanani A, Purohit D, Waghela D. Coastal saline soils of gujarat (India): Problems, reclamation measures and management strategies. In: Research developments in saline agriculture. Springer; 2019. pp.629-651.
49. Ikram M, Ali N, Jan G, Iqbal A, Hamayun M, Jan FG, et al. Trichoderma reesei improved the nutrition status of wheat crop under salt stress. J Plant Interact. 2019; 14: 590-602.
50. Barreto P, Counago RM, Arruda P. Mitochondrial uncoupling protein-dependent signaling in plant bioenergetics and stress response. Mitochondrion. 2020; 53: 109-120.
51. Ceusters N, Borland AM, Ceusters J. How to resolve the enigma of diurnal malate remobilisation from the vacuole in plants with crassulacean acid metabolism? New Phytol. 2021; 229: 3116-3124.
52. Condori-Apfata JA, Batista-Silva W, Medeiros DB, Vargas JR, Valente LML, Pérez-Díaz JL, et al. Downregulation of the E2 subunit of 2-oxoglutarate dehydrogenase modulates plant growth by impacting carbon-nitrogen metabolism in arabidopsis thaliana. Plant Cell Physiol. 2021; 62: 798-814.
53. Corpas FJ, González-Gordo S, Palma JM. Plant peroxisomes: A factory of reactive species. Frontiers in Plant Science. Front Plant Sci. 2020; 11: 853.
54. de Souza Chaves I, Feitosa-Araujo E, Florian A, Medeiros DB, da Fonseca-Pereira P, Charton L, et al. The mitochondrial NAD^+ transporter (NDT1) plays important roles in cellular NAD^+ homeostasis in Arabidopsis thaliana. Plant J. 2019; 100: 487-504.
55. Heinemann B, Hildebrandt TM. The role of amino acid metabolism in signaling and metabolic adaptation to stress-induced energy deficiency in plants. J Exp Bot. 2021; 72: 4634-4645.
56. Di Gioia F, Rosskopf EN, Leonardi C, Giuffrida F. Effects of application timing of saline irrigation water on broccoli production and quality. Agric Water Manag. 2018; 203: 97-104.
57. Ghodke P, Shirsat D, Thangasamy A, Mahajan V, Salunkhe V, Khade Y, et al. Effect of water logging stress at specific growth stages in onion crop. Int J Curr Microbiol Applied Sci. 2018; 7: 3438-3448.
58. Giuffrida F, Agnello M, Mauro RP, Ferrante A, Leonardi C. Cultivation under salt stress conditions influences postharvest quality and glucosinolates content of fresh-cut cauliflower. Sci Hortic. 2018; 236: 166-174.
59. Londo JP, Kovaleski AP, Lillis JA. Divergence in the transcriptional landscape between low temperature and freeze shock in cultivated grapevine (Vitis vinifera). Hortic Res. 2018; 5: 10.
60. Batayeva D, Labaco B, Ye C, Li X, Usenbekov B, Rysbekova A, et al. Genome-wide association study of seedling stage salinity tolerance in temperate japonica rice germplasm. BMC Genet. 2018; 19: 2.
61. Cao Z, Guo Y, Yang Q, He Y, Fetouh MI, Warner RM, et al. Genome-wide search for quantitative trait loci controlling important plant and flower traits in petunia using an interspecific recombinant inbred population of Petunia axillaris and Petunia exserta. G3 (Bethesda). 2018; 8: 2309-2317.
62. Chunthawodtiporn J, Hill T, Stoffel K, Van Deynze A. Quantitative trait loci controlling fruit size and other horticultural traits in bell pepper (Capsicum annuum). Plant Genome. 2018; 11: 160125.
63. Diouf IA, Derivot L, Bitton F, Pascual L, Causse M. Water deficit and salinity stress reveal many specific QTL for plant growth and fruit quality traits in tomato. Front Plant Sci. 2018; 9: 279.

64. Al-Ashkar I, Alderfasi A, El-Hendawy S, Al-Suhaibani N, El-Kafafi S, Seleiman MF. Detecting salt tolerance in doubled haploid wheat lines. Agronomy. 2019; 9: 211.
65. Jabeen Z, Hussain N, Irshad F, Zeng J, Tahir A, Zhang G. Physiological and antioxidant responses of cultivated and wild barley under salt stress. Plant Soil Environ. 2020; 66: 334-344.
66. Kordrostami M, Rabiei B, Hassani Kumleh H. Association analysis, genetic diversity and haplotyping of rice plants under salt stress using SSR markers linked to saltol and morpho-physiological characteristics. Plant Syst Evol. 2016; 302: 871-890.
67. Asghari R, Ahmadvand R. Salinity stress and its impact on morpho-physiological characteristics of aloe vera. Pertanika J Soc Sci Humanit. 2018; 411-422.
68. Ashraf M, Wu L. Breeding for salinity tolerance in plants. Crit Rev Plant Sci. 1994; 13: 17-42.
69. Ismail AM, Horie T. Genomics, physiology, and molecular breeding approaches for improving salt tolerance. Annu Rev Plant Biol. 2017; 68: 405-434.
70. Oladosu Y, Rafii MY, Abdullah N, Hussin G, Ramli A, Rahim HA, et al. Principle and application of plant mutagenesis in crop improvement: A review. Biotechnol Biotechnol Equip. 2016; 30: 1-16.
71. Yousefirad S, Soltanloo H, Ramezanpour S, Zaynalinezhad K, Shariati V. Salt oversensitivity derived from mutation breeding improves salinity tolerance in barley via ion homeostasis. Biol Plant. 2018; 62: 775-785.
72. Lethin J, Shakil SS, Hassan S, Sirijovski N, Töpel M, Olsson O, et al. Development and characterization of an EMS-mutagenized wheat population and identification of salt-tolerant wheat lines. BMC Plant Biol. 2020; 20: 18.
73. Mishra S, Singh B, Panda K, Singh BP, Singh N, Misra P, et al. Association of SNP haplotypes of HKT family genes with salt tolerance in Indian wild rice germplasm. Rice. 2016; 9: 1-13.
74. Siddique R. Impact of different media and genotypes in improving anther culture response in rice (oryza sativa) in Bangladesh. Eur Sci J. 2015; 11. DOI: 10.19044/esj.2015.v11n6p%25p.
75. Singh M, Nara U, Kumar A, Thapa S, Jaswal C, Singh H. Enhancing genetic gains through marker-assisted recurrent selection: From phenotyping to genotyping. Cereal Res Commun. 2021. DOI: 10.1007/s42976-021-00207-4.
76. Krishnamurthy S, Sharma P, Gautam R, Singh R, Singh Y, Mishra V, et al. Notification of crop varieties and registration of germplasm: Variety CSR56 (IET 24537). Indian J Genet. 2019; 79: 512-513.
77. Krishnamurthy S, Sharma P, Gautam R, Singh R, Singh Y, Mishra V, et al. Notification of crop varieties and registration of germplasm: Variety CSR60. Indian J Genet. 2019; 79: 513-514.
78. Singh VK, Singh BD, Kumar A, Maurya S, Krishnan SG, Vinod KK, et al. Marker-assisted introgression of saltol QTL enhances seedling stage salt tolerance in the rice variety “Pusa Basmati 1”. Int J Genomics. 2018; 2018: 8319879.
79. Bhandari A, Jayaswal P, Yadav N, Singh R, Singh Y, Singh B, et al. Genomics-assisted backcross breeding for infusing climate resilience in high-yielding green revolution varieties of rice. Indian J Genet. 2019; 79: 160-170.
80. Isayenkov SV, Maathuis FJ. Plant salinity stress: Many unanswered questions remain. Front Plant Sci. 2019; 10: 80.
81. Hasanuzzaman M, Bhuyan M, Zulfiqar F, Raza A, Mohsin SM, Mahmud JA, et al. Reactive oxygen species and antioxidant defense in plants under abiotic stress: Revisiting the crucial role of a universal defense regulator. Antioxidants. 2020; 9: 681.

82. Kolbert Z, Barroso JB, Brouquisse R, Corpas FJ, Gupta KJ, Lindermayr C, et al. A forty year journey: The generation and roles of no in plants. Nitric Oxide. 2019; 93: 53-70.
83. Arif Y, Singh P, Siddiqui H, Bajguz A, Hayat S. Salinity induced physiological and biochemical changes in plants: An omic approach towards salt stress tolerance. Plant Physiol Biochem. 2020; 156: 64-77.
84. Sharma A, Shahzad B, Kumar V, Kohli SK, Sidhu GPS, Bali AS, et al. Phytohormones regulate accumulation of osmolytes under abiotic stress. Biomolecules. 2019; 9: 285.
85. Çakır Aydemir B, Yüksel Özmen C, Kibar U, Mutaf F, Büyük PB, Bakır M, et al. Salt stress induces endoplasmic reticulum stress-responsive genes in a grapevine rootstock. PLoS One. 2020; 15: e0236424.
86. Bai G, Xie H, Yao H, Li F, Chen X, Zhang Y, et al. Genome-wide identification and characterization of ABA receptor PYL/RCAR gene family reveals evolution and roles in drought stress in Nicotiana tabacum. BMC Genomics. 2019; 20: 1-19.
87. Li Z, Lu H, He Z, Wang C, Wang Y, Ji X. Selection of appropriate reference genes for quantitative real-time reverse transcription PCR in betula platyphylla under salt and osmotic stress conditions. PLoS One. 2019; 14: e0225926.
88. Antoniou C, Zarza X, Gohari G, Panahirad S, Filippou P, Tiburcio AF, et al. Involvement of polyamine metabolism in the response of Medicago truncatula genotypes to salt stress. Plants. 2021; 10: 269.
89. Anwar A, Kim JK. Transgenic breeding approaches for improving abiotic stress tolerance: Recent progress and future perspectives. Int J Mol Sci. 2020; 21: 2695.
90. Zhao C, Zhang H, Song C, Zhu JK, Shabala S. Mechanisms of plant responses and adaptation to soil salinity. Innovation (Camb). 2020; 1: 100017.
91. Ezquer I, Salameh I, Colombo L, Kalaitzis P. Plant cell walls tackling climate change: Biotechnological strategies to improve crop adaptations and photosynthesis in response to global warming. Plants. 2020; 9: 212.
92. Ishaku GA, Tizhe DT, Bamanga RA, Afolabi ET. Biotechnology and drought stress tolerance in plants. Asian J Plant Sci. 2020: 34-46.
93. Singh AK, Dhanapal S, Yadav BS. The dynamic responses of plant physiology and metabolism during environmental stress progression. Mol Biol Rep. 2020; 47: 1459-1470.
94. Xie Z, Wang C, Zhu S, Wang W, Xu J, Zhao X. Characterizing the metabolites related to rice salt tolerance with introgression lines exhibiting contrasting performances in response to saline conditions. Plant Growth Regul. 2020; 92: 157-167.
95. Benjamin JJ, Lucini L, Jothiramshekar S, Parida A. Metabolomic insights into the mechanisms underlying tolerance to salinity in different halophytes. Plant Physiol Biochem. 2019; 135: 528-545.
96. Zhou HC, Shamala LF, Yi XK, Yan Z, Wei S. Analysis of terpene synthase family genes in camellia sinensis with an emphasis on abiotic stress conditions. Sci Rep. 2020; 10: 1-13.
97. Kopaczyk JM, Warguła J, Jelonek T. The variability of terpenes in conifers under developmental and environmental stimuli. Environ Exp Bot. 2020; 180: 104197.
98. Wittek B, Carnat G, Tison JL, Gypens N. Response of dimethylsulfoniopropionate (DMSP) and dimethylsulfoxide (DMSO) cell quotas to salinity and temperature shifts in the sea-ice diatom fragilariopsis cylindrus. Polar Biol. 2020; 43: 483-494.

99. Wang W, Mauleon R, Hu Z, Chebotarov D, Tai S, Wu Z, et al. Genomic variation in 3,010 diverse accessions of asian cultivated rice. Nature. 2018; 557: 43-49.

100. Shi S, Li S, Asim M, Mao J, Xu D, Ullah Z, et al. The arabidopsis calcium-dependent protein kinases (CDPKS) and their roles in plant growth regulation and abiotic stress responses. Int J Mol Sci. 2018; 19: 1900.