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Impact of Plant Growth Regulators (PGR's) in Rainfed Agriculture

Mohammed Azharuddin B.R.[1] and K. Murali[2]*
[1]Ph.D. Scholar, Department of Agronomy,
University of Agricultural Sciences, Bengaluru (Karnataka), India.
[2]Professor & Head, Department of Agronomy,
University of Agricultural Sciences, Bengaluru (Karnataka), India.

(Corresponding author: Mohammed Azharuddin B.R.)*
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ABSTRACT: Plant growth regulators (PGRs) have emerged as a crucial tool in rainfed agriculture to combat the various stresses that crops face in such environments. Rainfed agriculture relies solely on natural rainfall, which can be unpredictable and unevenly distributed, leading to challenges like water stress, nutrient stress, heat stress, weed stress, and climate change stress. PGRs aid plants in overcoming these stresses by enhancing root growth, nutrient uptake, defense mechanisms, cell elongation, photosynthesis, and soil stabilization. They also play a role in inhibiting weed growth while promoting overall plant growth. The endogenous biosynthesis of PGRs and their exogenous application as foliar agents offer potential solutions to mitigate the adverse effects of biotic and abiotic stresses in rainfed agriculture. By improving crop yield and quality, PGRs contribute significantly to sustainable agriculture practices in rainfed regions, supporting food security and livelihoods for millions of small-scale farmers worldwide. Utilisation of plant growth regulators in rainfed agriculture helps to enhance plant growth and productivity while increasing resilience to biotic stresses such as drought, salinity, and extreme temperatures. These regulators also contribute to sustainability by reducing the reliance on excessive water and fertilizers. However, the careful application of plant growth regulators is crucial, taking into account factors such as crop type, growth stage, and environmental conditions. By judiciously using these regulators, significant benefits can be realized in improving the livelihoods of rainfed farming communities.

Keywords: Plant growth regulators, Rainfed agriculture, Abiotic stress, Sustainability.

INTRODUCTION

Plant growth regulators (PGRs) have become an important tool in rainfed agriculture to mitigate different stresses that plants face in such environments. Rainfed agriculture is highly dependent on rainfall, which can be unpredictable and unevenly distributed. This results in various stresses on crops, such as water stress, nutrient stress, heat stress, weed stress and climate change stress. PGRs can help plants to overcome these stresses by promoting root growth, nutrient uptake, defence mechanism cell elongation, photosynthesis and soil stabilization (Zhang *et al.*, 2022). They can also inhibit weed germination and growth, while promoting plant growth. Endogenous biosynthesis of PGRs and their exogenous application as foliar agents have the potential to mitigate the adverse impacts of various biotic and abiotic stresses (Sabagh *et al.*, 2021). Overall, the use of PGRs in rainfed agriculture can improve crop yield and quality, making it a valuable tool for sustainable agriculture. Rainfed agriculture is a type of farming that relies solely on natural rainfall for crop production (Jaramillo *et al*., 2020). It is a traditional form of agriculture that is practiced in many regions of the world, particularly in developing countries. Rainfed agriculture is often associated with small-scale farmers who have limited resources and rely on subsistence farming to meet their basic needs. The success of rainfed agriculture is highly dependent on the amount and timing of rainfall, which can be unpredictable and variable from year to year. In areas with low rainfall, farmers may use techniques such as rainwater harvesting and conservation agriculture to maximize crop yields (Zheng *et al.*, 2023). Despite its challenges, rainfed agriculture plays an important role in providing food security for millions of people around the world. In India, rainfed agriculture is the backbone of the rural economy, providing livelihoods for millions of small and marginal farmers. According to the Ministry of Agriculture and Farmers Welfare, about 60% of the country's net sown area is rainfed, covering around 96 million hectares. Rainfed agriculture in India faces several challenges, including erratic rainfall patterns, soil degradation, low soil fertility, and limited access to irrigation facilities (Rao *et al*., 2013). The farmers in these areas often lack access to modern inputs such as high-yielding seeds, fertilizers, and pesticides, leading to low crop yields.

According to National Rainfed Area Authority (2022), 61 per cent of India's farmer population comes under rainfed area, rainfed agriculture nearly accounts 40 per cent of the total food production of India. According to National Commission on Agriculture (1972) and National Agriculture Research Project (NARP), out of 127 agroclimatic zones in India 73 are predominantly rainfed.

Plant growth regulators (PGRs). Plant growth regulators (PGRs) are chemicals that are used to regulate the growth and development of plants. They are widely used in agriculture to improve crop yields, increase plant resistance to stress, and enhance the quality of produce. In rainfed agriculture, PGRs can be used to improve the efficiency of water use by plants, allowing them to grow and develop even in conditions of limited water availability (Wakchaure *et al*., 2020). They can also be used to promote root growth, which helps plants to access water and nutrients from deeper soil layers. Some common PGRs used in rainfed agriculture include gibberellins, auxins, cytokinin, and abscisic acid. These chemicals can be applied to plants as foliar sprays or soil drenches, depending on the specific needs of the crop. However, the use of PGRs in agriculture is not without risks. Overuse or misuse of these chemicals can lead to negative impacts on the environment and human health. Therefore, it is important to use PGRs judiciously and in accordance with recommended guidelines and best practices (Wu *et al.,* 2023). Rainfed agriculture is the practice of growing crops in areas where rainfall is the primary source of water for plant growth. While it is a crucial source of food for millions of people worldwide, it faces several challenges that includes Erratic rainfall, Soil erosion, Waterlogging, Drought, Pest and disease outbreaks, Limited access to irrigation, Poor infrastructure.

Major types of stress in rainfed agriculture include: Drought stress - Lack of rainfall or prolonged dry periods can result in drought stress, which can significantly reduce crop yields, Heat stress - High temperatures can negatively affect plant growth and development, leading to reduced crop yields, Salinity stress - Soil salinity can cause water stress and nutrient imbalances in crops, resulting in reduced productivity, Nutrient stress - Soil nutrient deficiencies or imbalances can limit plant growth and development, leading to reduced crop yields, Weed stress - Weeds can compete with crops for resources such as water, nutrients, and sunlight, reducing crop yields (Fahad *et al*., 2017).

Types of plant growth regulators

1. Plant growth promoters: Plant growth promoters are substances or microorganisms that are used to enhance the growth and development of plants. They can include biofertilizers, growth hormones, and beneficial microorganisms that help to improve soil health and fertility, increase nutrient uptake, and stimulate plant growth and yield. Plant growth promoters can be applied through various methods such as foliar sprays, soil application, and seed treatment (Efthimiadou *et al*., 2020). Types of plant growth promoters are Auxin, Gibberellins and Cytokinin.

2. Plant growth inhibitors: Plant growth inhibitors are substances or conditions that slow down or prevent the growth and development of plants. They can include herbicides, allelochemicals, and environmental factors such as drought, low light intensity, and extreme temperatures. Plant growth inhibitors can interfere with various metabolic processes in plants, such as photosynthesis, cell division, and hormone synthesis, leading to stunted growth, reduced yield, and even plant death (Ahluwalia *et al.,* 2021). Plant growth inhibitors can be applied through various methods such as foliar sprays, soil application, and seed treatment. Types of plant growth inhibitors are Abscisic acid and Ethylene.

Commercial extraction of Plant growth regulators

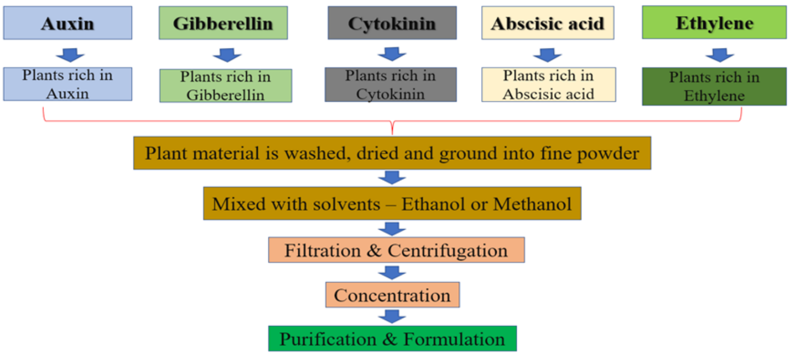

Fig. 1. Flowchart of commercial extraction of PGRs.

One common method for extracting PGRs from plants is through solvent extraction. Plant tissue is ground and mixed with a solvent such as ethanol or methanol. The mixture is then filtered to remove any solid particles and the solvent is evaporated to leave behind a concentrated extract containing PGRs. Another method is through steam distillation. Plant material is placed in a distillation apparatus and steam is passed through it. The steam carries the auxin out of the plant material and into a condenser, where it is collected as a liquid. In some cases, auxin can also be extracted using chromatography techniques, which separate the compound from other plant compounds based on their chemical properties. This method can produce very pure PGRs, but is more complex and expensive than solvent extraction or steam distillation (Crouch and Staden 1993).

Plant growth regulators:

Auxin: Auxin is a plant hormone that is responsible for regulating growth and development in plants. It is produced in the tips of shoots and roots and then transported to other parts of the plant. Auxin promotes cell elongation, root formation, and the development of fruit and flowers. It also plays a role in phototropism, which is the bending of a plant towards a light source. Auxin levels can be affected by environmental factors such as light, gravity, and temperature (Casal and Estevez 2021). Overall, auxin is an important hormone for the growth and development of plants.

Auxin helps in lateral root growth of the plants where auxin activity is dependent on nitrate concentration and NRT1.1 transporter. NRT1.1 transporter supress the lateral root primordia emergence and growth of young lateral roots in the absence or low nitrate concentration (<0.23mM) indirectly affecting or suppressing auxin activity in the plants. Decreased concentration of nitrate suppresses the auxin transport by NRT1.1. This NRT1.1 transporter protein helps in auxin movement towards parent root rather than helping towards lateral root primordia emergence region where laterals root development happens whereas at high nitrate concentration, auxin transport by NRT1.1 is inhibited towards the parent root, which gets accumulated in the lateral root primordia and it stimulates that lateral root growth of the plant (Bouguyon *et al*., 2016).

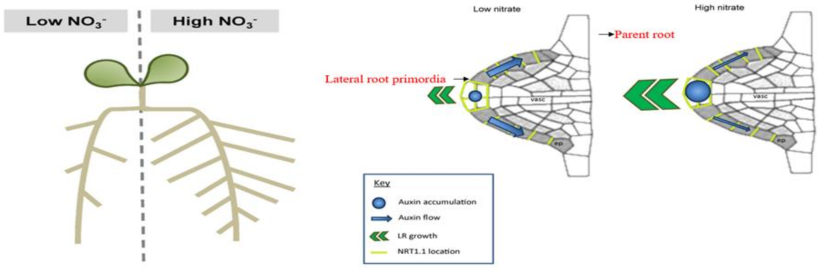

Fig. 2. Movement of auxin influenced by nitrate concentration.

Vidoz *et al*. (2010) studied the effect of ethylene and auxin on adventitious root formation under flooding conditions in tomato crop. The Fig. 3 shows a hypocotyl region showing adventitious root primordia and adventitious root emergence before and after 24 hrs, 72 hrs and 7 days of flooding treatment respectively. The flow chart explains that flooding condition results in ethylene entrapment by water which is the first signal to the plants warning about waterlogging. With the help of never ripe (NR) receptor auxin transportation is stimulated. Auxin starts to accumulates in the stem and which again triggers the ethylene synthesis with the help of *ACS* 3 and *ACS* 7 gene. This accumulated auxin in the stem will be transported to flooded parts of the plants which helps in growth of lateral roots that allows the plant to recover after the damage due to flood stress or waterlogging. In sub Fig. 3a, it is observed that the wild tomato plants without dgt gene under submergence of 24hrs, 72 hrs and 7 days shows slow and reduced development of adventitious roots where as wild tomato with dgt transferred gene shows good growth of adventitious roots in submerged condition.

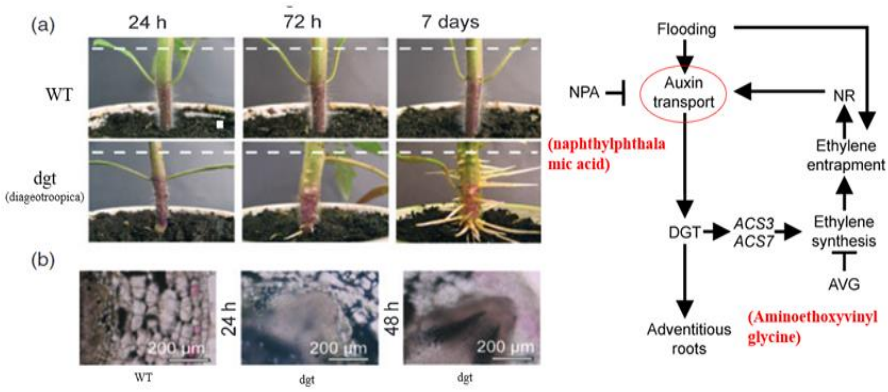

Fig. 3. Influence of ethylene and auxin on adventitious root formation under flooding conditions in tomato crop.

Jeber *et al.* (2019) recorded that compound treatment of organic acids and naphthalene acetic acid (OA + NAA) statistically enlarge the flag leaf (36.37 cm^2) than other treatments. Control treatment shows the least flag area (20.59 cm^2). Application of AA + NAA resulted in highest ratio of chlorophyll (48.63 %). There were significant differences between treatment and the least chlorophyll average with the control and OA treatment. They made no significant differences between the no. of tillers but for plant height trait. NAA application resulted in the highest plant height (95.9 cm) and control resulted in the least (78.8 cm). It may be due to the fact that organic, amino acids and dioxins are rich in a wide range of minerals that important of plant growth. The existence of nitrogen with these elements plays a positive role in increasing the activity of meristem tissue and cellular division. Nasab *et al*. (2020) showed that application of superabsorbent and auxin on plant height, pod length, seed yield, biological yield and harvest index were significant. The increase of superabsorbent application up to 120 kg ha^{-1} led to significant increase of above traits in comparison to without application of superabsorbent treatment and application of 15 ppm auxin caused the significant increase of plant height, pod length, seed yield, biological yield and harvest index comparison to without application of auxin. It is may due to superabsorbent decrease the loss of water i.e., transpiration loss and increase consumption efficiency of crops and auxin application are directly involved in biosynthesis of materials and can produce more plant cells and consequently more dry matter and store them in grains as reservoirs and leads to increase in yield and yield parameters. Application of NAA @ 30 ppm @ 80 DAS increased plant height, leaf area index, seed cotton yield, biological yield and harvest index because of foliar spray of NAA stimulates cell elongation and promotion of cell division which in turn results into stem elongation whereas application of mepiquat chloride (MC) @ 200 ppm decreased plant height because mepiquate chloride reduces the cell elongation by its inhibitory action on biosynthetic pathway of gibberellins (Sabale *et al.*, 2017).

Gibberellins (GAs): Gibberellins are a class of plant hormones that regulate various aspects of plant growth and development. They were first discovered in Japan in the 1930s as a result of research into a disease affecting rice plants, which was later found to be caused by a fungus that produced a substance that promoted plant growth. Gibberellins are involved in many processes, including seed germination, stem elongation, flowering, and fruit development. They also play a role in leaf expansion, root growth, and the response of plants to environmental stress (Castro *et al*., 2022). One of the most important functions of gibberellins is their ability to promote stem elongation. This is achieved by stimulating cell division and elongation in the stem, which leads to increased internode length. This is particularly important for agricultural crops such as wheat, rice, and barley, where increased stem length can lead to higher yields. Gibberellins also play a role in seed germination by breaking down the seed coat and activating enzymes that promote the growth of the embryo.

Chen *et al*. (2019) recorded that three individual transgenic events with different increased *AtGox1* expression levels were identified. Among these, transgenic lines #1 had the highest expression level of *AtGox1* followed by other transgenic lines. GA_1 content was reduced by 49.5 - 74 per cent in transgenic maize compared to the wild type (WT) plants due to the activation of *AtGox1* in transgenic maize created a dominant semi-dwarf phenotype and there was dramatic change in plant height from the jointing stage to mature stage when drought was induced and results supported the notion that over-expression of *AtGox1* could create a GA – deficient phenotype in maize. The results revealed that application of GA_3 at 75 ppm showed maximum plant height (194.90 cm), shoot length (15.57 cm), leaf area (7.37 cm^2) and number of flowers per plant (29.01) Phawa *et al.* (2017). The effectiveness of GA_3 might be due to its role in promoting growth and stimulated the rapid cell elongation in meristematic zone of vegetative plant organs. The improvement of the length was due to both increased number and length of cells. The increase in leaf area was probably due to the fact that gibberellin stimulates the activity of auxin resulting in production of more number of leaves thereby increasing leaf area.

Cytokinin: Cytokinin are a group of plant hormones that play a crucial role in regulating cell division and growth in plants. They are synthesized in the roots, and then transported to other parts of the plant, where they bind to specific receptors on the cell surface. Once bound, cytokinin activate a signalling pathway that leads to the activation of genes involved in cell division and growth. Cytokinin are involved in many processes in plants, including the development of leaves, roots, and flowers, as well as the regulation of apical dominance and the delay of senescence. They work in conjunction with other plant hormones, such as auxins, to regulate plant growth and development. For example, cytokinin promote cell division and growth in the presence of auxins, while auxins promote elongation and differentiation (Sosnowski *et al.*, 2023). Cytokinin have a variety of applications in agriculture and horticulture. They can be used to promote the growth of crops, increase yields, and improve the quality of fruits and vegetables. They can also be used to delay senescence and extend the shelf life of harvested crops.

Isopentenyl transferase gene *(IPT)* helps in delayed senescence, more root and shoot biomass, dropped fewer flowers, maintains higher chlorophyll content and higher photosynthetic rates. The author studied the effect of *IPT* gene showing tolerance against water deficit. Isopentenyl transferase gene was taken from Agrobacterium tumefaciens to develop drought tolerant plant by reducing water deficit in plants under drought condition. cotton yield per plant is higher in transgenic lines i.e., *IPT*2, *IPT*5, *IPT*6 and *IPT*9 compared to the wild type and segregating non transgenic plants under reduced irrigation (induced drought stress) on par to the yield obtained under regular irrigation. The same trend was observed with no. of bolls per plant. These results indicate that water deficit induced expression of an isopentenyl transferase gene in cotton could significantly improve drought tolerance (Kuppu *et al*., 2013).

Hamad *et al*. (2023) observed that implementation of kinetin displayed highest significant and positive values for plant height, seed yield and harvest index when compared to control. Application of kinetin @ mg L^{-1} positively enhanced the plant height, seed yield and harvest index to an extent of 3 per cent, 14 per cent and 14.5 per cent respectively compared to non-treated plants. It may be due to kinetic plays an important role in promoting cell division, shoot meristem size, regulates leaf primordia and increase the root hairs.

Abscisic acid (ABA): ABA is a plant hormone that plays a crucial role in regulating various physiological processes in plants, particularly in response to stress. It is synthesized in the leaves, stems, and roots of plants, and is transported to other parts of the plant via the xylem and phloem.ABA is involved in many processes in plants, including seed development and dormancy, stomatal closure, and the regulation of plant growth and development in response to environmental stresses such as drought, cold, and salt (Finkelstein, 2013). ABA acts as a signal molecule that triggers a cascade of responses within the plant, leading to changes in gene expression and physiological responses (Tuteja, 2007).

Hu *et al*. (2022) studied the effects of exogenous ABA and MT application (single or combined) on cotton leaf photosynthetic carbon metabolism and yield under drought. Melatonin is an anti-oxidant, it acts as a plant growth regulator similar to IAA. Results revealed that single ABA or MT application significantly improved plant water status under drought. Both DS_M and DS_{A+M} treatments effectively increased *Pn* by 39.9 per cent and 67.4 per cent respectively compared with DS.

Ethylene: Ethylene is a plant hormone that plays a critical role in regulating various physiological processes in plants, particularly in response to environmental stimuli. It is synthesized in various parts of the plant, including leaves, stems, roots, and flowers, and is transported throughout the plant via the air. Ethylene is involved in many processes in plants, including fruit ripening, senescence, and abscission, as well as responses to biotic and abiotic stresses such as pathogen attack, drought, and flooding (Iqbal *et al*., 2017). Ethylene acts as a signal molecule that triggers a cascade of responses within the plant, leading to changes in gene expression and physiological responses (Binder, 2020). Ethylene also helps plants respond to biotic and abiotic stresses. When plants are under stress, such as during drought or pathogen attack, ethylene levels increase, triggering a range of responses that help the plant adapt to the stress. Overall, ethylene is a critical plant hormone that helps plants regulate growth and development in response to environmental stimuli (Iqbal *et al*., 2017).

Sedaghat *et al*. (2023) studied the role of ethephon in fig fruit ripening under rain-fed condition. In this, fig fruits were sprayed three times by foliar application at 15-days intervals. The highest fruit ripening percentage occurred with second time application of ethephon @ 200 mg L^{-1}. Fruit diameter was also increased after application of ethephon @ 200 mg L^{-1} after 7 weeks after flowering. Here the ethephon sprayed on fig in rainfed condition got degraded to ethylene and hastened the fruit ripening.

Benavides *et al*. (2016) studied the effect of heat stress on relative water content of rice genotypes and on crop stress index. In Fig. 4 heat stress treatment registered the lowest value in both genotypes. A significant increase in relative water content was registered in rice plants of both genotypes treated with PGRs. Application of cytokinin under heat stress recorded higher relative water content than other treatments. It is explained that rice plants in heat stress treatment showed higher stress index values (0.816) whereas lower was recorded between 0.6 to 0.7 with application of PGRs. the impact of the combined heat stress and foliar plant growth regulators spray in rice plants. Under heat stress stomatal conductance (gs) is reduced chlorophyll content is reduced and increased the lipid peroxidation. Whereas application of PGRs like cytokinin, brassinosteriods ameliorate the effect of combined heat stress in rice plants which helps in increasing the stomatal conductance, increases chlorophyll content, reduces the damage caused by heat stress to the photosystem II and decreases the lipid peroxidation.

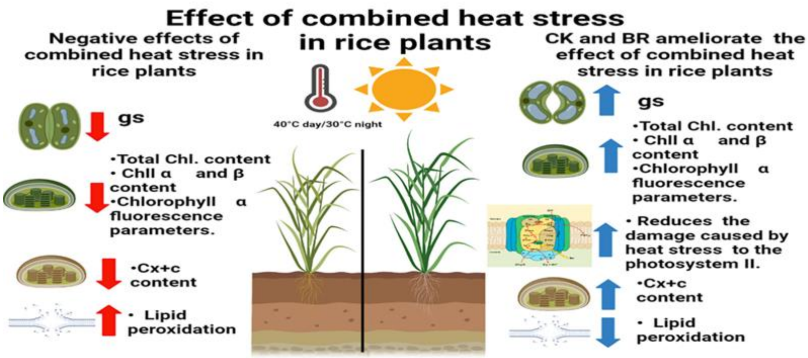

Fig. 4. Concept model of the impact of the combined heat stress and foliar plant growth regulators sprays in rice plants.

CONCLUSIONS

The use of plant growth regulators in rainfed agriculture has shown promising results in improving growth and productivity. These regulators help plants to overcome biotic stresses like drought, salinity and extreme temperatures hereby increasing their resilience and productivity. The use of these regulators also reduces the need for excessive water and fertilizers, making rainfed agriculture more sustainable. However, it is important to note that the application of plant growth regulators should be done carefully, considering crop type, growth stage and environmental conditions. The judicious use of plant growth regulators can play a vital role in livelihoods of rainfed farming communities.

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