International Journal of Botany Studies
www.botanyjournals.com
ISSN: 2455-541X
Received: 05-04-2025, Accepted: 06-05-2025, Published: 21-05-2025
Volume 10, Issue 5, 2025, Page No. 26-31

Impact of plant growth regulators and fungicides on non-enzymatic antioxidant potential in *Ocimum basilicum* L

Dr. Kavina J[1*], Dr. Anusha J[2], Dr. Kumaresubitha T[1]
[1] Assistant professor, Department of Botany, Pachaiyappa's college, Chennai, Tamil Nadu, India
[2] Assistant professor, Department of Pharmacology, KMCH Institute of Health Sciences and Research, Coimbatore, Tamil Nadu, India

Abstract
The present study investigates the effect of plant growth regulators (PGRs) and fungicide treatments on the non-enzymatic antioxidant potential of *Ocimum basilicum* L. (basil), a medicinal herb known for its antioxidant properties. The research aimed to evaluate the influence of gibberellic acid (GA3), propiconazole (PPZ), and their combinations with beneficial microbes on key non-enzymatic antioxidants, namely total phenols, ascorbic acid, and reduced glutathione, across different growth stages of the plant. The experiment was carried out with treatments applied at three growth stages: 25, 50, and 75 days after planting (DAP). Results showed a significant increase in the total phenol, ascorbic acid, and reduced glutathione contents in treated plants compared to the control group. The application of PPZ demonstrated a stronger enhancement in these antioxidants than GA3, with the highest increase observed at 75 DAP in the propiconazole-treated plants. Specifically, propiconazole treatment resulted in a 121.35% increase in reduced glutathione content over the control. Additionally, a positive correlation was observed between the enhanced antioxidant levels and the overall growth parameters of the plants. These findings suggest that the application of PGRs like GA3 and fungicides such as propiconazole can significantly boost the non-enzymatic antioxidant defenses in *Ocimum basilicum*, potentially improving its medicinal value.

Keywords: *Ocimum basilicum*, plant growth regulators, propiconazole, non-enzymatic antioxidants, ascorbic acid, reduced glutathione

Introduction

Ocimum basilicum Linn., commonly known as basil, is a well-known and extensively studied medicinal plant belonging to the family Lamiaceae. Native to tropical regions of Asia, Africa, South America, and Central America, it is widely cultivated for its aromatic leaves and essential oil production. Depending on the variety, basil may be an annual or sometimes a perennial herb, with plants typically reaching heights between 30 to 150 cm.

The plant is valued for its rich phytochemical profile, notably tannins and terpenic derivatives, which are responsible for its therapeutic potential. Both fresh and dried leaves are used in the formulation of various medicinal preparations including infusions, fluid extracts, syrups, powders, essences, and juices. The herb is traditionally recognized for its stomachic, antispasmodic, antitussive, insect-repelling, and tonic properties. In folk medicine, the juice extracted from fresh basil leaves is used to treat ailments such as fever, diarrhea, and ear pain. Additionally, basil flowers have stimulant, carminative, antispasmodic, diuretic, and demulcent properties, while the seeds are known for their anti-dysenteric effects.

Essential oil extracted from *O. basilicum* exhibits antibacterial, antifungal, and insecticidal activities. Recent studies have further revealed its potential in treating hyperlipidemia and its roles as an antioxidant, neuroprotective, anti-inflammatory, vasodilator, and hepatoprotective agent. These findings highlight the need for clinical trials to explore its efficacy in disease prevention and as an adjunct in therapeutic interventions.

The application of plant growth regulators (PGRs) has shown promise in enhancing the yield of vegetative parts that produce secondary metabolites. Among these regulators, gibberellic acid (GA_3) is notable for its influence on various physiological processes, such as seed germination, stem elongation, and leaf expansion (Swain and Singh, 2005) [34]. It also promotes uniform flowering, reduces the time to flowering, and increases both the number and size of flowers (Khassawneh *et al*., 2006) [1].

Another important PGR, abscisic acid (ABA), plays a regulatory role in processes such as embryo maturation, seed development and germination, cell division and elongation, stomatal function, root development, floral transition, and stress tolerance (Giraudat *et al*., 1994) [14]. The common methods for PGR application include foliar sprays and soil drenches. However, soil drenching is considered more effective for the stable production of secondary metabolites in medicinal plants (Jaleel *et al*., 2006) [19].

In addition to GA_3 and ABA, triazole compounds such as paclobutrazol and propiconazole have been shown to induce significant morphological and physiological changes in *Ocimum* species. These include shoot growth inhibition, enhanced root elongation, increased chlorophyll content, altered carbohydrate metabolism, and elevated enzymatic activity (Jaleel *et al*., 2007a). Specifically, propiconazole has been associated with increased enzyme activity in creeping bentgrass (Zhang and Schmidt, 2000) [37] and altered enzyme production in *Trametes versicolor* (Serge *et al*., 2008) [32]. Furthermore, the combined application of GA_3, ABA, and triazole compounds has been shown to enhance antioxidant production in medicinal plants such as *Mentha piperita* (Kavina *et al*., 2011) [21].

Review of Literature

Plant Growth Regulators (PGRs)

Plant growth regulators are natural or synthetic compounds that influence plant physiological processes at very low

concentrations. These substances play critical roles in regulating plant growth and development and are also involved in the biosynthesis of secondary metabolites (Kakimoto, 2003) [20]. Numerous synthetic PGRs with diverse growth-modulating properties have been developed, and new compounds continue to emerge (Al-Khassawneh *et al*., 2006) [1]. These regulators are widely used in agriculture to control vegetative and reproductive growth, as well as various physiological activities in plants (Srivastava and Srivastava, 2007) [33]. Furthermore, they have been implicated in the biosynthesis of secondary metabolites such as alkaloids (Verpoorte *et al*., 1997) [36].

Gibberellic Acid (GA_3)

Gibberellins are a group of naturally occurring plant hormones involved in various developmental processes (Celik *et al*., 2008). GA_3, one of the most studied gibberellins, is known for promoting seed germination, stem and hypocotyl elongation, leaf expansion, floral induction, and uniform flowering. It also enhances flower size and number, and stimulates hydrolytic enzyme activity in cereal grains (Akazawa *et al*., 1990; Matsuoka, 2003; Swain and Singh, 2005; Khassawneh *et al*., 2006; Srivastava and Srivastava, 2007) [1, 33, 34]. GA_3 plays a pivotal role in shoot growth regulation, and young leaves are the primary sites of its biosynthesis (Grochowska and Hodun, 1997; Finkelstein *et al*., 2002) [9].

Application of GA_3 has been shown to enhance the aerial biomass in *Viola* and double the flower diameter in *Tulipa* (Rebers *et al*., 1994) [31]. In *Saussurea lappa*, GA_3 treatment significantly improved root and shoot growth (Kaushal and Rana, 2004). It has also been used to manipulate flowering time and induce off-season cropping in plants like strawberry (Paroussi *et al*., 2002) [30]. GA_3 plays a role in dormancy regulation, as observed in potato tubers, where endogenous levels fluctuate during natural tuber formation (Suttele, 2004). However, excessive application may lead to undesirable elongation and reduced plant quality (Giraudat *et al*., 1994; Hopkins, 1995) [14]. Moreover, gibberellins affect enzyme activity and secondary metabolite production, such as enhancing amaranthine synthesis and promoting anthocyanin accumulation in *Hibiscus sabdariffa* (Laloraya *et al*., 1976; Mizukami *et al*., 1988) [23].

Triazole Compounds

Triazoles are primarily known as antifungal agents but also function as potent plant growth regulators by modifying hormonal balances, including GA, ABA, and cytokinins (Fletcher *et al*., 2000; Islam *et al*., 2004) [11]. They inhibit gibberellin and ergosterol biosynthesis (Rademacher, 2000), leading to significant morphological and physiological effects such as reduced shoot elongation, enhanced root growth, increased cytokinin and ABA levels, and modified sterol composition.

Although triazoles may induce stress-like symptoms (Gaspar *et al*., 2002) [13], they can enhance plant tolerance to abiotic stresses such as drought, UV radiation, and extreme temperatures, earning them the label of "multi-protectants" (Fletcher *et al*., 2000; Gupta *et al*., 2004) [12]. For instance, triazoles have protected greenhouse-grown wheat seedlings against high-temperature stress (Booker *et al*., 1991) [4].

Several commercial triazole derivatives, such as triadimefon (Bayleton), propiconazole (Banner), paclobutrazol (Bonzi), and uniconazole (Sumagic), serve dual roles as fungicides and growth retardants (Fletcher, 1986). Triadimefon inhibited *Vicia faba* growth at rust-control concentrations (Tuske, 1983), while propiconazole reduced leaf area in pecan (Wetztein, 2002) and early seedling growth in redroot pigweed (Hanson, 2003).

Triazoles block key steps in the *ent*-kaurene oxidation pathway, inhibiting gibberellin biosynthesis and ABA catabolism (Still and Pill, 2003; Rademacher, 1997; Ranwala *et al*., 2005). Their stress-protective effects are linked to hormonal shifts, such as elevated cytokinins, transient ABA increase, and reduced ethylene production (Mackay *et al*., 1990; Raghava and Raghava, 1998; Sopher *et al*., 1999). One of the most consistent effects is height reduction (Thakur and Thakkur, 1993).

Triadimefon reduced shoot weight but increased root weight and root/shoot ratio in radish (Muthukumaraswamy *et al*., 2000). It also increased leaf biomass in bean and cowpea (Panneerselvam *et al*., 1998; Gopi *et al*., 1998, 1999) [29], and improved root mass in cucumber seedlings (Feng *et al*., 2003). Triazole-treated plants such as maize and *Brassica napus* showed reduced leaf area and increased leaf thickness and wax deposition (Khalil *et al*., 1990; Child *et al*., 1993). Tebuconazole had similar effects in groundnut and *Solenostemon rotundifolius* (Asami *et al*., 2000; Kishorekumar *et al*., 2006).

Additionally, triazoles enhanced chlorophyll content and induced various physiological and biochemical changes in carrot (Gopi *et al*., 2005, 2007) [15]. Their impact on gibberellin biosynthesis and carbohydrate status improved stress resilience, delayed senescence, and promoted cytokinin and ABA synthesis (Leul and Zhou, 1998, 1999; Li and Yang, 2004). Diniconazole increased ABA content and stress gene expression in *Nicotiana tabacum* during dehydration (Kitahata *et al*., 2005), and similar results were seen in maize treated with tetraconazole (Angela *et al*., 1997). Triazoles also promoted adventitious root formation in barley and soybean cuttings (Ozmen *et al*., 2003; Zhang *et al*., 2007).

Materials and Methods

Plant Material and Experimental Site

The medicinally important plant species *Ocimum basilicum* Linn. was selected for the present study. High-quality seeds were procured from agricultural seed stores located in Erode, Tamil Nadu. The plant growth regulators (PGRs) used included Gibberellic acid (GA_3), obtained from Sigma Chemicals, Bangalore, and Propiconazole (PPZ), a triazolic fungicide with growth-regulating properties, acquired from Syngenta.

The experimental work was conducted at the greenhouse garden of the Department of Botany, Pachaiyappa's College, Chennai. The average ambient temperature during the study was approximately 32/26 °C (day/night), and relative humidity ranged from 60–75%.

Cultivation Methods

Seeds were sown in pots during December 2021 under greenhouse conditions. The potting mixture used was composed of red earth, sand, vermicompost, and coir compost in a 1:1:1:1 ratio, ensuring a balanced supply of nutrients. Plants were irrigated daily at regular intervals, and standard agronomic and plant protection measures were followed throughout the study period.

Treatment Application

Preliminary experiments were conducted using varying concentrations of GA_3 (2.5, 5.0, 7.5, and 10.0 μM L^{-1}) and

PPZ (2, 5, 10, 15, and 20 mg L^{-1}) to determine the optimal levels for treatment. Among the tested concentrations, 5 µM L^{-1} GA_3 and 10 mg L^{-1} PPZ significantly increased the dry weight of *Ocimum* plants. Higher concentrations led to reduced growth and dry matter accumulation, while lower concentrations produced negligible effects. Consequently, 5 µM L^{-1} GA_3 and 10 mg L^{-1} PPZ were selected for further investigation.

Biochemical Analysis

Estimation of Total Phenol Content

Total phenolic content was estimated using the method of Malick and Singh (1980). Fresh plant tissue (500 mg) was homogenized in 10 ml of 80% ethanol using a mortar and pestle. The homogenate was centrifuged at 10,000 rpm for 20 minutes, and the supernatant was evaporated to dryness. The residue was reconstituted in 5 ml of distilled water. An aliquot (2 ml) of the extract was mixed with 0.5 ml of Folin–Ciocalteu reagent, followed by 2 ml of 20% sodium carbonate solution after 3 minutes. The mixture was heated in boiling water for 1 minute, cooled, and the absorbance was recorded at 650 nm using a spectrophotometer. Total phenolic content was calculated using a gallic acid standard curve and expressed as mg g^{-1} dry weight.

Estimation of Ascorbic Acid (AA) Content

Ascorbic acid content was measured following the method of Omay *et al*. (1979). One gram of fresh plant material was ground in 5 ml of 10% trichloroacetic acid (TCA), centrifuged at 3,500 rpm for 20 minutes, and the supernatant was pooled and made up to 10 ml. To 0.5 ml of the extract, 1 ml of DTC reagent (2,4-dinitrophenylhydrazine–thiourea–$CuSO_4$) was added and incubated at 37 °C for 3 hours. Then, 0.75 ml of ice-cold 65% H_2SO_4 was added, and the mixture was left at 30 °C for 30 minutes. The developed color was measured at 520 nm using a spectrophotometer (Hitachi U2001). Ascorbic acid concentration was determined using a standard curve and expressed in mg g^{-1} dry weight.

Estimation of Reduced Glutathione (GSH) Content

The content of reduced glutathione was estimated using the method described by Griffith and Meister (1999) [16]. Fresh plant material (200 mg) was homogenized in 2 ml of 2% metaphosphoric acid and centrifuged at 17,000 rpm for 10 minutes. The supernatant was neutralized with 0.6 ml of 10% sodium citrate. The assay mixture (1 ml) was prepared by combining 100 µl of the extract, 100 µl of distilled water, 100 µl of 5,5'-dithiobis-(2-nitrobenzoic acid) (DTNB), and 700 µl of NADPH. After incubating at 25 °C for 3–4 minutes, 10 µl of glutathione reductase enzyme was added. The absorbance was measured at 412 nm using a spectrophotometer, and GSH content was expressed as µg g^{-1} fresh weight.

Results

Non-Enzymatic Antioxidants

Total Phenol Content

In Root

The total phenol content in root tissues increased progressively with plant age across all treatments. The highest increase was recorded at 75 days after planting (DAP) under propiconazole (PPZ) treatment, showing a 127.21% rise over the control. The lowest increase was observed in GA_3-treated plants at 25 DAP, with a 102.59% increase over control (Table 1).

In Stem

Phenol content in stem tissues significantly increased with plant age in all treatments. Maximum enhancement was seen in PPZ-treated plants at 75 DAP, with a 122.97% increase over control. The lowest increase was observed in GA_3-treated plants at 25 DAP (100.73% over control) (Table 1).

In Leaf

Leaf tissues showed an increasing trend in phenol content with plant maturity. PPZ treatment resulted in the highest increase (131.99%) at 75 DAP. GA_3-treated plants showed the minimum increase (101.72%) at 25 DAP (Table 1).

Table 1: Effect of GA_3 and PPZ on Total Phenol Content in Root, Stem, and Leaf of *Ocimum basilicum* at Different Growth Stages (mg/g FW)

Growth Stage (DAP)	Root - Control	Root - GA_3	Root - PPZ	Stem - Control	Stem - GA_3	Stem - PPZ	Leaf - Control	Leaf - GA_3	Leaf - PPZ
25	3.85 ± 0.061	4.05 ± 0.072	4.12 ± 0.035	4.12 ± 0.002	4.15 ± 0.006	4.26 ± 0.016	4.06 ± 0.036	4.14 ± 0.014	4.22 ± 0.077
50	3.96 ± 0.005	4.19 ± 0.047	4.43 ± 0.019	6.18 ± 0.008	6.35 ± 0.017	7.46 ± 0.012	4.60 ± 0.128	5.58 ± 0.054	5.88 ± 0.175
75	4.19 ± 0.002	5.30 ± 0.007	5.33 ± 0.009	5.31 ± 0.109	6.13 ± 0.036	6.53 ± 0.023	4.72 ± 0.008	5.57 ± 0.002	6.23 ± 0.003

Note: Values are given as mean ± SD of six experiments in each group and are expressed in mg/g fresh weight (FW).

Ascorbic Acid (AA) Content

Table 2: Effect of GA_3 and PPZ on Ascorbic Acid Content in Root, Stem, and Leaf of *Ocimum basilicum* at Different Growth Stages (mg/g FW)

Growth Stage (DAP)	Root - Control	Root - GA_3	Root - PPZ	Stem - Control	Stem - GA_3	Stem - PPZ	Leaf - Control	Leaf - GA_3	Leaf - PPZ
25	1.93 ± 0.017	2.14 ± 0.018	2.31 ± 0.018	0.925 ± 0.021	0.927 ± 0.021	1.125 ± 0.020	0.97 ± 0.027	1.05 ± 0.021	1.07 ± 0.024
50	3.96 ± 0.026	4.71 ± 0.022	5.74 ± 0.026	2.158 ± 0.017	2.265 ± 0.012	2.397 ± 0.017	2.18 ± 0.022	2.467 ± 0.022	2.93 ± 0.026
75	3.06 ± 0.109	3.56 ± 0.125	4.27 ± 0.129	1.625 ± 0.021	1.701 ± 0.014	2.332 ± 0.021	3.23 ± 0.022	3.38 ± 0.022	3.87 ± 0.031

Note: Values are given as mean ± SD of six experiments in each group and are expressed in mg/g fresh weight (FW).

In Root
AA content increased in root tissues at all stages. The highest increase was recorded in PPZ-treated plants at 75 DAP (127.34%), and the lowest increase was observed with GA_3 at 50 DAP (106.13%) (Table 2).

In Stem
Increased AA levels were observed in stem tissues across treatments. The highest enhancement was seen with PPZ at 75 DAP (119.21%), while the lowest was under GA_3 treatment at 50 DAP (104.95%) (Table 2).

In Leaf
Leaf AA content followed a similar trend, with the highest content at 75 DAP under PPZ treatment (131.80%). The least increase was in GA_3-treated plants at 75 DAP (103.36%) (Table 2).

Reduced Glutathione (GSH) Content

Table 3: Effect of GA_3 and PPZ on Reduced Glutathione Content in Root, Stem, and Leaf of *Ocimum basilicum* at Different Growth Stages (mg/g FW)

Growth Stage (DAP)	Root - Control	Root - GA_3	Root - PPZ	Stem - Control	Stem - GA_3	Stem - PPZ	Leaf - Control	Leaf - GA_3	Leaf - PPZ
25	1.01 ± 0.091	1.09 ± 0.015	1.18 ± 0.073	1.19 ± 0.015	1.22 ± 0.002	1.32 ± 0.012	0.93 ± 0.002	0.98 ± 0.001	1.00 ± 0.001
50	1.62 ± 0.011	1.64 ± 0.008	1.93 ± 0.022	1.43 ± 0.002	1.61 ± 0.263	1.64 ± 0.193	0.93 ± 0.004	1.10 ± 0.002	1.22 ± 0.005
75	1.66 ± 0.002	1.75 ± 0.004	1.99 ± 0.005	1.52 ± 0.014	1.57 ± 0.001	1.97 ± 0.014	1.15 ± 0.025	1.29 ± 0.002	1.59 ± 0.004

Note: Values are given as mean ± SD of six experiments in each group and are expressed in mg/g fresh weight (FW).

In Root
GSH levels in root tissue increased with age. PPZ treatment led to the highest content at 75 DAP (116.01% over control). GA_3 treatment showed the lowest increase at 50 DAP (101.23%) (Table 3).

In Stem
Stem GSH content showed maximum increase under PPZ treatment at 75 DAP (129.61%), while the lowest increase was with GA_3 at 50 DAP (102.79%) (Table 3).

In Leaf
The reduced glutathione content in leaf tissue increased with plant age in both control and treated plants. Propiconazole treatment significantly enhanced glutathione content compared to gibberellic acid. The highest increase (121.35% over control) was observed at 75 DAP in propiconazole-treated plants (Table 3).

Fig 1: Variations of growth in *Ocimum basilicum* under the treatments with Gibberellic acid, Propiconazole along with Control (Individual plants view on 50 DAP).

Discussion
The present investigation was conducted to determine the effects of Gibberellic acid (GA3) and Propiconazole (PPZ) on the growth and antioxidant status of *Ocimum basilicum*. The results on non-enzymatic antioxidant activities are discussed below.

Non-Enzymatic Antioxidants
Total Phenol
The total phenol content significantly increased with GA3, PPZ, *P. fluorescens*, and *P. aeruginosa* treatments in *G. superba* at all stages of growth. This finding is consistent with previous studies where PBZ treatment increased total phenol content in the leaves of mango seedlings (Murti and Upreti, 2003). It has been suggested that peroxidase could act as an efficient H2O2 scavenging system in plant vacuoles in the presence of phenolics and reduced ascorbate (Zancani and Nagy, 2000). Sgherri *et al.* (2003) hypothesized a cycle where H2O2 is scavenged by phenolic compounds, which are oxidized to phenoxyl radicals. These radicals then reduce ascorbic acid into monodehydro ascorbate.
Increased phenol content was previously reported in *Coleus* with hexaconazole treatments (Lakshmanan *et al*., 2007) [22]. Triazole compounds not only protect plants from stress but also induce stress-like symptoms. A significant part of the antioxidants produced by plants in response to stress is secondary metabolites, including simple and complex phenolic compounds derived primarily via the phenylpropanoid pathway (Dixon and Paiva, 1995) [6]. The two aromatic amino acids, phenylalanine and tyrosine, play a major role as precursors for a wide variety of phenolics and tocopherol (Liu *et al*., 2006). A highly positive correlation was found between antioxidant capacity and phenolic content, indicating that phenolic compounds are major contributors to antioxidant activity in medicinal plants (Siddarthan, 2007).

Ascorbic Acid
The ascorbic acid content increased in *G. superba* with GA3, PPZ, *P. fluorescens*, and *P. aeruginosa* treatments in all parts of the plants. The non-enzymatic antioxidant contents play major roles in maintaining the balance between free radical production and elimination (Lin *et al*., 2006). In plants, the ascorbic-glutathione cycle is crucial in

free radical scavenging and multiple stress responses (Drazkiewicz *et al*., 2003) [7]. Ascorbic acid is an important antioxidant that functions as the 'terminal antioxidant' because the redox potential of the ascorbate/monodehydro ascorbate pair is lower than that of most bioreactive radicals (Scandalios *et al*., 1997). Uniconazole treatments increased the antioxidant levels, including ascorbic acid, in tomato seedlings, thereby protecting the membrane by preventing or reducing oxidative damage (Senaratna *et al*., 1988). Increases in ascorbic acid were also reported in paclobutrazol-treated *Citrus lemon* (Jain *et al*., 2002) [17] and in *Catharanthus roseus* with GA3 treatment (Jaleel *et al*., 2007).

Reduced Glutathione

The reduced glutathione content increased with GA3, PPZ, *P. fluorescens*, and *P. aeruginosa* treatments in *G. superba*. PPZ treatments significantly increased reduced glutathione content at all growth stages, with a slight difference compared to GA3. Reduced glutathione content increased with the application of pesticides and herbicides in *Euphorbia esula* (Davis and Swanson, 2001). The increase in reduced glutathione is linked to its ability to scavenge singlet oxygen, peroxides, and hydroxyl radicals, and its involvement in the recycling of ascorbic acid in the ascorbate-glutathione pathway in chloroplasts (Foyer *et al*., 1993). Reduced glutathione plays a key role in the protection against oxidative stress through the ascorbate-glutathione disulfide redox status (Alscher *et al*., 1997). Increased non-enzymatic antioxidants can be associated with the plant's protective mechanisms against oxidative stress. As major antioxidant species in plants, ascorbic acid, reduced glutathione, and α-tocopherol contents vary in different subcellular compartments, depending on the intensity of stress (Gaspar *et al*., 2002) [13].

Hexaconazole increased the reduced glutathione content in *Carrot* (Gopi *et al*., 2007) [15]. Triadimefon and paclobutrazol increased the reduced glutathione content in *C. roseus* (Jaleel *et al*., 2007). GA up to 1.2 µM induced changes in glutathione metabolism, which was associated with anthocyanin content in *G. superba* cell cultures (Ohlsson and Berglund, 2001). TDM treatment increased the reduced glutathione content in citrus fruits (Jain *et al*., 2002) [17]. The increase in non-enzymatic antioxidants, enzymatic antioxidants, and root alkaloid content suggests that GA3 and PBZ profoundly influence regulatory mechanisms in *Catharanthus* (Jaleel *et al*., 2008).

Summary and Conclusion

Plant growth regulators (PGRs) are chemical compounds, either naturally produced by plants or synthetically synthesized, that regulate plant growth and development at very low concentrations. Since most plant growth and development processes are regulated by natural plant hormones, it is hypothesized that PGRs also play a role in the biosynthesis of secondary metabolites. Triazole compounds, used for their fungicidal properties, also possess plant growth-regulating properties and modulate the balance of important plant hormones such as GA, ABA, and cytokinins. Triazole derivatives, collectively known as sterol biosynthesis inhibitors, have been developed for use as both plant growth regulators and fungicides.

The PGRs used in this study, GA3 and Propiconazole (a triazole group fungicide), were effective in increasing non-enzymatic antioxidant potentials at all stages of growth. This enhancement helps the plant to increase secondary metabolites and its medicinal properties. With the observed increase in antioxidants, there is likely a corresponding increase in essential oil content, which will be investigated in future studies.

References

1. Al-Khassawneh NM, Karam NS, Shibli RA. Growth and flowering of black iris (*Iris nigricans* Dinsm.) following treatment with plant growth regulators. Sci Hortic,2006:107:187–193.
2. Baliah TN, Baby UL, Premkumar R. Screening of Azospirillum strains on the growth of tea plants under nursery condition. 6th International PGPR workshop, Calicut, India, 2003, 78–82.
3. Bandara PMS, Tanino KK. Paclobutrazol enhances mini tuber production in Norland potatoes. J Plant Grow Regul,1995:14:151–155.
4. Booker HM, Gillespie TJ, Hofstra G, Fletcher RA. Uniconazole induced thermo tolerance in wheat seedlings is mediated by transpirational cooling. Physiol Plant,1991:81:335–342.
5. Divya Nair V, Gopi R, Mohankumar M, Kavina J, Panneerselvam R. Effect of triadimefon: A triazole fungicide on oxidative stress defense system and eugenol content in *Ocimum tenuiflorum* L. Acta Physiol Plant,2012:34:599–605.
6. Dixon RA, Paiva NL. Stress-induced phenylpropanoid metabolism. Plant Cell,1995:7:1085–1097.
7. Drazkiewicz M, Polit ES, Krupa Z. Response of ascorbate glutathione cycle to excess copper in *Arabidopsis thaliana* L. Plant Sci,2003:164:195–202.
8. Ella ES, Ito O, Tanaka K. Role of ascorbate and active oxygen scavenging enzymes in post submergence injury in rice. Ann Sci Con Fed Crop Sci Soc Philippines,1998:23:82.
9. Finkelstein RR, Gampala SSL, Rock CD. Abscisic acid signaling in seeds and seedlings. Plant Cell,2002:14:15–45.
10. Finnie JF, Van Staden J. Isolation of colchicines from Sandersonia aurantica and Gloriosa superba: Variation in alkaloid levels of plants grown *in vivo*. J Plant Physiol,1991:138(6):691–695.
11. Fletcher RA, Hofstra G. Triazoles as potential plant protectants. In: Berg D, Plempel M, editors. Sterol Biosynthesis Inhibitors. Ellis Horwood Limited, 1988, 321–331.
12. Fletcher RA, Gilley A, Sankhla N, Davis TM. Triazoles as plant growth regulators and stress protectants. Hort Review,2000:24:56–138.
13. Gaspar T, Kevers C, Bailleul F. The role of ascorbic acid in the plant's defence against stress. Physiol Plant,2002:114:113–118.
14. Giraudat J, Parcy F, Bertauche N. Efficacy of paclobutrazol, propiconazole, and tetraconazole as stress protectants in wheat seedlings. Plant Grow Regul,1994:21:169–175.
15. Gopi R, Jaleel CA, Sairam R, Lakshmanan GMA, Gomathinayagam M, Panneerselvam R. Differential effects of hexaconazole and paclobutrazol on biomass, electrolyte leakage, lipid peroxidation, and antioxidant potential of Daucus carota L. Coll Surf B Biointer,2007:60:180–186.

16. Griffith OW, Meister A. Potent and specific inhibition of glutathione synthesis by buthionine sulfoximine (S-N-butylhomocysteine sulfoximine). J Biol Chem,1999:254:7558–7560.
17. Jain M, Bhatnagar S. Increase in ascorbic acid content in paclobutrazol treated citrus lemon. J Agric Sci,2002:122:13–16.
18. Jaleel CA, Salem MA. Fate of biochemical components of Catharanthus roseus after treatment with different plant growth regulators. Ast Jou Agri Eng,2010:1(2):45–53.
19. Jaleel CA, Gopi R, Lakshmanan GM, Panneerselvam R. Triadimefon induced changes in the antioxidant metabolism and ajmalicine production in Catharanthus roseus (L.) G. Don. Plant Sci,2006:171:271–276.
20. Kakimoto T. Preparation and signal transduction of cytokinin. Annu Rev Plant Biol,2003:54:605–627.
21. Kavina J, Gopi R, Panneerselvam R. Plant growth regulators and fungicide alter growth and biochemical contents in Mentha piperita Linn. Intern Jou Res Plant Sci,2011:1(2):15–22.
22. Lakshmanan GMA, Jaleel CA, Gomathinayagam M, Panneerselvam R. Changes in antioxidant potential and sink organ dry matter with pigment accumulation induced by hexaconazole in Plectranthus forskholic Briq. C R Biol,2007:330:814–820.
23. Laloraya M, Srivastan HN, Guruprasad KN. Recovery of gibberellic acid inhibition of betacyanin biosynthesis by pigment precursors. Planta,1976:128:275–276.
24. Langille AR, Helper PR. Effects of three anti-gibberellin growth retardants on tuberization of induced and non-induced Katahdin potato leaf bud cuttings. Am Potato J,1992:60:131–141.
25. Manivannan P, Jaleel CA, Sankar B, Kishorekumar A, Somasundaram R, Lakshmanan GMA, *et al*. Growth, biochemical modifications, and proline metabolism in Helianthus annuus L. as induced by drought stress. Coll Surf B Biointer,2007:59:141–149.
26. Meister A. Glutathione, ascorbate, and cellular protection. Cancer Res,1994:54:1969S–1975S.
27. Omaye ST, Turnbull JD, Sauberilich HE. Selected methods for the determination of ascorbic acid in animal cells, tissues, and fluids. Meth Enzymol,1979:11:3–11.
28. Panneerselvam R, Muthukumarasamy M, Karikalan L. Triadimefon enhances growth and net photosynthetic rate in NaCl stressed plants of Raphanus sativus L. Photosyn,1997:34:605–609.
29. Panneerselvam R, Muthukumarasamy M, Rajan SN. Amelioration of NaCl stress by triadimefon in soybean seedlings. Biol Plant,1998:41:133–137.
30. Paroussi G, Voyiatzis DG, Paroussis E, Drogoudi PD. Growth, flowering, and yield responses to GA of strawberry grown under different environmental conditions. Sci Hort,2002:96:103–113.
31. Rebers M, Romeijn G, Knegt E, Vander Plas LHW. Effect of exogenous gibberellins and pactobutuzol on floral stalk growth of tulip sprouts isolated from cold tulip bulbs. Physiol Plant,1994:92:661–667.
32. Serge L, Jacquot JP, Gerardin P, Gelhaye E. Effects of propiconazole on extra-cellular enzymes involved in nutrient mobilization during Trametes versicolor wood colonization. Wood Sci Tech,2008:42:169–177.
33. Srivastava NK, Srivastava AK. Influence of gibberellic acid on 14CO2 metabolism, growth, and production of alkaloids in Catharanthus roseus. Photosynthetica,2007:45:156–160.
34. Swain SM, Singh DP. Tales from sly dwarves: novel functions of gibberellins in plant development. Trends Plant Sci,2005:10:123–129.
35. Verma JP, Yadav J, Tiwari K, Lavakush, Singh V. Impact of plant growth promoting bacteria on crop production. Intern J Agri Res,2010:5(4):945–983.
36. Verpoorte R, Vander Heijden RR, Moreno PRH. Biosynthesis of terpenoid indole alkaloids in Catharanthus roseus cells. In: Cordell GA, editor. Academic San Diego,1997:49:221–299.
37. Zhang X, Schmidt RE. Hormone-containing products impact on antioxidant status of tall fescue and creeping bentgrass subjected to drought. Crop Sci,2000:40:1344–1349.
38. Zhao Y. The role of local biosynthesis of auxin and cytokinin in plant development. Curr Opin Plant Biol,2008:11:16–22.