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Cultivating Efficiency: The Power of Plant Growth Regulators in Pakistani Agriculture

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Abstract

Plant growth regulators (PGRs) are a class of agrochemicals that profoundly influence plant development and yield. This review examines how exogenously applied PGRs – notably gibberellic acid (GA_3), naphthalene acetic acid (NAA), paclobutrazol (PBZ), 6-benzylaminopurine (6-BA), and nitrophenolate compounds – affect the growth and productivity of major crops in Pakistan. Emphasis is given to chili (Capsicum annuum L.), bitter gourd (Momordica charantia L.), maize and sweet corn (Zea mays L.), tomato (Solanum lycopersicum), hybrid rice (Oryza sativa L.), and wheat (Triticum aestivum L.). We synthesize findings from field studies under Pakistani agro-climatic conditions, highlighting physiological effects of PGRs on flowering, sex expression, stress tolerance, and source–sink relations. Generally, PGR applications at critical growth stages led to improved plant architecture, enhanced fruit set, and significant yield increases across crops. For instance, foliar NAA sprays reduced blossom drop in chili and bitter gourd, increasing fruit number and size, while combinations of auxin and GA_3 alleviated heat-induced fruiting problems in tomato. In cereals, PBZ and 6-BA applications at heading in rice boosted spikelet formation and grain filling, whereas foliar nitrophenolates in wheat increased tillering, grain weight, and overall yield. The review discusses optimal concentrations and timings for each crop, mechanisms underlying the PGR responses (such as delayed leaf senescence and improved antioxidant enzyme activity), and the potential agronomic benefits. Finally, we provide recommendations for PGR use in Pakistani agriculture to achieve better yield outcomes, along with considerations for future research and farmer adoption.

Key Words: Plant growth regulators (PGRs); crop yield; stress tolerance; chili; bitter gourd; tomato; rice; wheat

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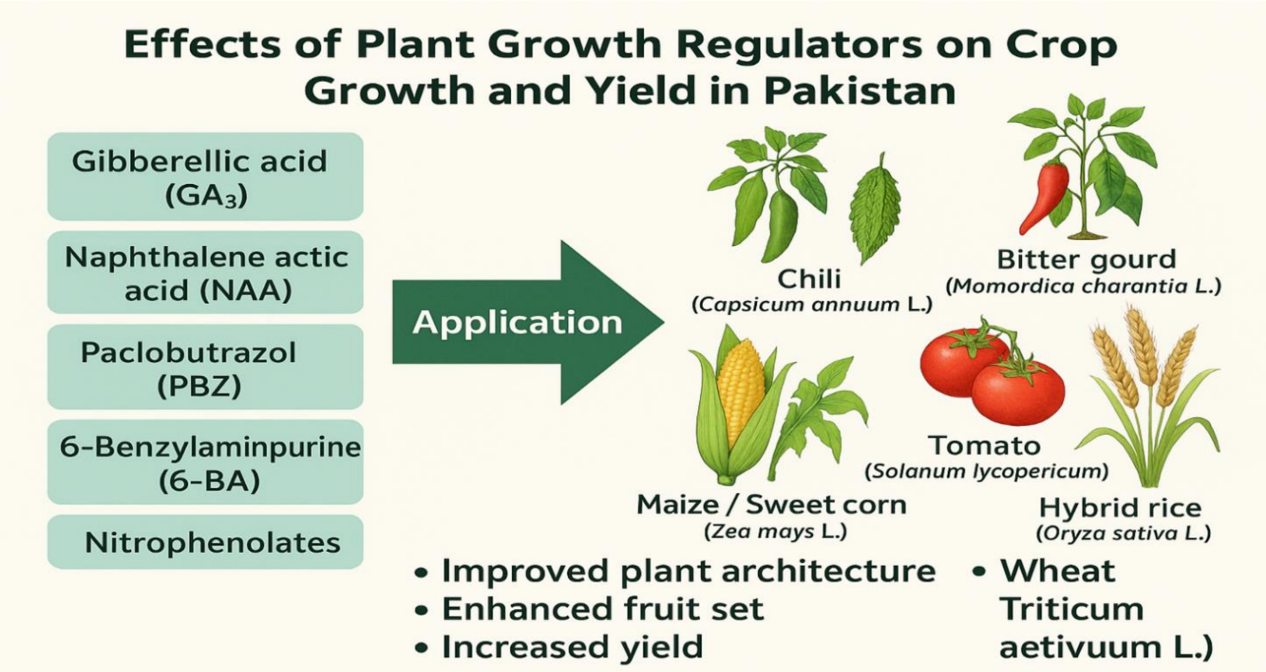
Graphical Abstract



Introduction

Crop yields in Pakistan are often constrained by environmental stresses and developmental limitations, prompting interest in plant growth regulators (PGRs) as tools to enhance productivity. Plant growth regulators (PGR) are chemical compounds involved in plant intercellular communication, particularly in actively growing tissues. They regulate cell division, root formation, embryogenesis, fruit development, ripening, and tolerance to biotic and abiotic stresses (Khan, 2021).

PGRs are organic compounds (natural or synthetic hormones) that, in very small concentrations, modify plant growth and development processes (Taiz et al., 2015). Unlike bulk fertilizers, PGRs fine-tune physiological pathways – they can promote or inhibit specific developmental events such as cell elongation, branching, flowering, fruit set, and senescence

(Davies, 2010). These regulators represent a "new generation of agrochemicals" following the widespread use of pesticides and fertilizers. In practical terms, exogenous PGR treatments have been used to improve source–sink relationships in plants, enhance stress tolerance, and ultimately increase crop yields (Rademacher, 2015).

In Pakistan's agroclimatic context, PGR applications hold particular promise for addressing local yield-limiting factors. For example, high-temperature stress in summer causes severe blossom drop in chili and tomato, reducing fruit set (Ali et al., 2018). Hormonal imbalances are partly responsible for such abscission, suggesting that applying growth hormones (auxins or gibberellins) could mitigate losses (Sadasivam & Manickam, 2019). Similarly, cucurbit crops like bitter gourd exhibit gendered flowering; an excess of staminate (male) flowers or delayed pistillate (female) flowering can limit fruit production. Here, PGRs that influence sex expression (such as ethylene releasers or gibberellins) may help shift the balance toward fruitful female flowers (Islam et al., 2016).

In cereal crops, lodging (stem buckling) and abiotic stresses like drought and salinity are major concerns that can be addressed by growth regulators. Triazole compounds like paclobutrazol (PBZ) reduce excessive stem elongation, thereby lowering lodging risk, and also induce stress tolerance mechanisms (Fletcher et al., 2000). Indeed, PGR sprays are routinely used in some countries to shorten internodes and protect grain crops from lodging while increasing yield (Shah et al., 2019). Foliar PGR application has been shown to prolong grain filling and increase kernel size in cereals, even under drought conditions (Hussain et al., 2021). This dual role of PGRs – enhancing growth under optimal conditions and buffering against stress – is valuable for improving crop productivity in regions like Pakistan, where climatic variability and resource limitations challenge farmers.

Recent research in Pakistan and comparable environments has explored various PGRs on the country's staple and horticultural crops. Gibberellic acid (GA_3), an endogenous gibberellin, is widely studied for its role in stem elongation and fruit development (Shahniza Saiin et al., 2020). Auxins such as NAA (1-naphthaleneacetic acid) are known to promote cell division and vascular flow, thereby improving flower retention and fruit set (Anjum et al., 2017). Synthetic cytokinin 6-BA (6-benzylaminopurine) can delay leaf senescence and promote sink activity by cell division in reproductive organs (Habib et al., 2014). Growth inhibitors like PBZ (a triazole) counter gibberellin effects to produce sturdier, more drought-tolerant plants (Rademacher, 2015). Additionally, nitrophenolates (salts of nitrophenol derivatives) have emerged as PGR biostimulants; these phenolic compounds act as antioxidant protectants and metabolic enhancers in plants (Ali et al., 2020). Commercial formulations of nitrophenol derivatives (such as sodium 5-nitroguaiacolate, ortho-nitrophenolate, and para-nitrophenolate) have been tested on field crops for yield improvement (Zafar et al., 2019).

The goal of this review is to analyze how such PGRs affect crop growth and yield in Pakistani agriculture. We focus on major crops – chili, bitter gourd, tomato, maize (including sweet corn), hybrid rice, and wheat – summarizing experimental findings on yield-related outcomes and physiological responses. By synthesizing results across studies in the world, we aim to identify patterns in PGR efficacy (which regulators work best for which crop and trait), and to discuss practical recommendations for farmers and researchers. The following sections outline the common research methodologies used in these studies, present the results and discussion for each crop, and finally offer conclusions and crop-specific recommendations for PGR use in Pakistan.

Materials and Methods

Literature Search and Selection: This review compiles data from multiple peer-reviewed studies conducted in Pakistan (or under similar subtropical conditions) that examined PGR effects on the aforementioned crops. We included recent research articles (2013–2025) that reported quantitative impacts of exogenous PGR treatments on growth, yield, or physiological parameters. Key sources were field or greenhouse experiments published in agricultural journals. For comprehensiveness, both horticultural crops (vegetables) and field crops (cereals) are covered, ensuring representation of the major plant hormone groups (auxins, gibberellins, cytokinins, growth inhibitors, and synthetic stimulants like nitrophenols).

General Experimental Designs: Across the studies reviewed, experiments were typically laid out in randomized complete block designs (RCBD) or factorial designs with replications to ensure statistical validity. Field trials were conducted at research stations or university farms in Pakistan, with plots receiving different PGR treatments and a control (no PGR). For example, Jilani et al. (2025) tested ten treatments on chili in an RCBD with three replicates, while Ghani et al. (2013) employed a factorial combination of PGR concentration and application timing on bitter gourd. Crop management (planting density, fertilization, pest control) was standardized within each study to isolate PGR effects.

PGR Treatments: The PGRs examined included GA_3, NAA, PBZ, 6-BA, ethylene-releasing agent ethephon (trade name Ethrel), indole-3-butyric acid (IBA), 4-chlorophenoxyacetic acid (4-CPA, a synthetic auxin), and mixtures of nitrophenolates. Treatments were applied as foliar sprays at specific growth stages optimal for each crop's development. For instance, foliar sprays at early vegetative stages (2–4 leaf stage) or at floral bud initiation were common in vegetable crops, whereas cereals often received PGR at the heading or anthesis stage. Some studies compared timing of application (e.g. PGR applied during vegetative vs. reproductive stage), as well as concentration gradients (e.g. 0, 50, 100, 150 ppm) to determine dose-response. A control treatment (water or no spray) was always included for baseline comparison. Table 1 summarizes the PGR treatments and application stages in the core studies reviewed.

Data Collection: Common growth metrics measured were plant height, number of branches or tillers, days to flowering, and flower counts. Yield components assessed included fruit set percentage, fruit length and weight (for vegetables), number of grains per spike or spikelets per panicle (for cereals), 1000-grain weight, and ultimately yield per plant, per plot, or per hectare. Some studies also recorded physiological data such as antioxidant enzyme activities (e.g. superoxide dismutase, peroxidase) and malondialdehyde (MDA) content to gauge stress and senescence effects. Data were analyzed using ANOVA, and mean differences among treatments were determined by LSD or Duncan's multiple range tests at the 5% significance level. Each study's results were reported with appropriate statistical notation (e.g. different letters indicating significant differences) and often presented in tables or figures, which we reference in this review.

Table 1: Overview of PGR treatments in key studies

Crop (Study)	PGRs tested and doses	Application stage(s)	Experimental design (replicates)
Chili pepper (Jilani *et al.*, 2025)	NAA @ 30, 60, 90 ppm; GA_3 @ 50, 100, 150 ppm; combinations of NAA+GA_3	Foliar at vegetative and early flowering stage (Kharif season)	RCBD, 10 treatments (incl. control), 3 reps
Bitter gourd (Ghani *et al.*, 2013)	GA_3 @ 25, 50, 75 ppm; Ethrel @ 400, 500, 600 ppm; NAA @ 50, 100, 150 ppm	Foliar at S1: 2-leaf, S2: 4-leaf, S3: flowering bud stage (factorial)	RCBD, 9 PGR treatments × 3 timings, 3 reps
Tomato (summer) (Islam *et al.*, 2013)	4-CPA @ 20 ppm; GA_3 @ 20 ppm; 4-CPA + GA_3 @ 20 ppm each (plus control)	Foliar: GA_3 at 21 days after transplant; 4-CPA at anthesis (high-temperature season)	RCBD, 4 treatments, 6 reps
Sweet corn (Saiin *et al.*, 2020)	IBA @ 50, 100 mg/L; GA_3 @ 50, 100 mg/L; (plus water control)	Foliar at vegetative 6–8 leaf vs. reproductive (tasseling) stage	Split-plot (timing × PGR × dose), 4 reps (Malaysia)
Hybrid rice (Pan *et al.*, 2013)	GA_3 @ 20 mg/L; PBZ @ 50 mg/L; 6-BA @ 30 mg/L; control (water)	Foliar at heading stage (early booting) for two cultivars	Split-plot (cultivar × PGR), 4 reps (South China)
Wheat (Ahmad *et al.*, 2022)	Nitro-phenolate mixture (5-nitroguaiacolate + ortho- & para-nitrophenolate) at 100, 150, 200 ppm	Foliar sprays at tillering and booting stages (greenhouse pot and plot trials)	Two sets: pot study & 1 m^2 plot trials, repeated over 2 years, 3 reps

Note: All studies included an untreated control. RCBD = Randomized Complete Block Design. S1, S2, S3 = growth stages as defined in each study.

By drawing on these methodologically robust experiments, we ensure that the results discussed are statistically reliable and pertinent to Pakistan's agricultural conditions.

Results and Discussion:

The work done on different crops regarding PGR in Pakistan and in the word is discussed in the following portion.

Chili (Capsicum annuum L.)

In Pakistan, Jilani et al. (2025) evaluated the effects of two plant growth regulators (PGRs)—NAA (an auxin) and GA_3 (a gibberellin)—on chili production. The findings revealed that NAA applied at 60 ppm produced the most promising results, leading to the tallest plants (65.6 cm), the earliest flowering (~42 days), the highest number of flowers per plant (19), and the greatest yield (149.3 kg per plot). GA_3 at 100 ppm was the second most effective treatment, enhancing branching and producing a yield of approximately 139 kg per plot. Interestingly, the combination of NAA and GA_3 did not outperform the single treatments, suggesting that excessive hormone levels or interactions between the two regulators may disrupt the plant's natural physiological balance. These results closely align with international findings. For instance, studies from Nepal, Bangladesh, and India consistently demonstrate that NAA applied in the range of 40–60 ppm enhances fruit number, fruit set, vitamin C content, plant height, and yield (Jilani et al., 2025; Alam et al., 2021; Dey et al., 2022). Similarly, GA_3 has been shown to promote vegetative growth and yield, though its effectiveness is highly context-dependent. In Saudi Arabia and Egypt, GA_3 at 20–30 ppm improved flowering and capsaicin levels under plastic tunnel cultivation, while in Mexico, GA_3 at 10 mg L^{-1} increased jalapeño yields only when combined with calcium and potassium fertilizers (Hafez et al., 2020; Ramírez-Rivera et al., 2021). Mechanistically, auxins such as NAA primarily trigger fruit set, while gibberellins like GA_3 help prevent flower drop, explaining why moderate doses of NAA (such as Pakistan's 60 ppm) provide the strongest reproductive boost. Conversely, mixing treatments or using excessive concentrations can counteract these benefits by disturbing hormonal equilibrium (Serrani et al., 2007).

Table 2: Chili (Capsicum annuum L.) - PGR Comparisons

PGR	Best Dose	Main Outcome	Context	Reference
NAA	60 ppm	Tallest plants (65.6 cm), earliest flowering (~42 days), most flowers (19/plant), highest yield (149.3 kg/plot)	Pakistan, open field (Gomal Univ., 2022; pub. 2025)	Jilani et al., 2025
NAA	40 ppm	Maximum fruit number in cv. 'Suryamukhi'	Nepal, field	Alam et al., 2021
NAA	40–60 ppm	Increased fruit set, ascorbic acid, plant height, yield	Bangladesh & India, field	Dey et al., 2022
GA_3	100 ppm	Higher branching and yield (~139 kg/plot), but below NAA 60 ppm	Pakistan, open field	Jilani et al., 2025
GA_3	20–30 ppm	Increased flowers, fruits, capsaicin content	Saudi Arabia & Egypt, plastic tunnels	Hafez et al., 2020
GA_3	10 mg L^{-1} (with Ca/K fertilizer)	Improved jalapeño yield and quality	Mexico, greenhouse	Ramírez-Rivera et al., 2021
Mechanistic	Auxin → GA sequence	Auxin triggers fruit set; GA reduces abscission	Sweet pepper, physiology	Serrani et al., 2007

It is concluded from the above experiments, for open-field chili grown in hot regions, applying NAA at 40–60 ppm during flowering helps reduce flower drop. GA_3 can be used at lower doses—20–30 ppm in tunnels or 10 mg L^{-1} along with calcium or potassium fertilizer in greenhouses—when extra branching and vigor are desired, but it's always wise to test small blocks first since results can vary depending on the setup.

Bitter Gourd (Momordica charantia L.)

Bitter gourd vines naturally produce a high proportion of male flowers early in their growth cycle, with female flowers appearing later, which leads to a low fruit set ratio. Plant growth regulators (PGRs) have proven effective in correcting this imbalance by promoting femaleness, advancing flowering, and thereby enhancing yields. In Pakistan, Ghani et al. (2013) demonstrated that gibberellin (GA_3) at 25 ppm induced the earliest flowering (~46 days compared to 51 days in the control), while GA_3 at 75 ppm significantly improved fruit size and yield, reaching approximately 1.5 kg per vine compared to only 0.22 kg in the control—a six- to sevenfold increase. Interestingly, in bitter gourd, GA_3 uniquely increased female flowers, in contrast to cucumber where it promotes maleness. Among the tested PGRs, NAA (auxin) applied at 100 ppm during the four-leaf stage proved the most effective overall, boosting yield to 1.75 kg per vine compared with 0.19 kg in the control (an eightfold increase). NAA also enhanced the fruit set percentage, shifted sex expression toward femaleness, and accelerated fruit maturation by reducing the interval between flowering and harvest. Ethrel (an ethylene releaser) further promoted female flower formation but delayed the onset of flowering (50–51 days compared to 41 days in the control), which extended crop duration. Although yields improved under Ethrel, they remained lower than those achieved with NAA or GA_3. Mechanistically, GA_3 advances flowering and enhances vine vigor, producing more nodes for female flowers and larger fruits; NAA promotes the differentiation of female flowers and improves fruit retention, leading to the highest fruit set and yield; while Ethrel suppresses male flowers and enforces femaleness but at the cost of delayed crop timing. These findings correspond well with international evidence from cucurbits such as cucumber, pumpkin, and bottle gourd, where auxins (NAA 50–100 ppm) consistently enhance femaleness and fruit set (Wang & Zeng, 1996; Singh et al., 2012). However, bitter gourd represents a unique case in which GA_3, unlike in cucumber, stimulates femaleness, as confirmed by studies in both Pakistan and China.

Table 3 Bitter Gourd (Momordica charantia L.)- PGR Comparisons

PGR	Best Dose	Main Outcome	Context	Reference (APA)
GA_3	25 ppm	Earliest flowering (~46 days vs 51 in control); earlier maturity	Pakistan, Faisalabad field trial	Ghani et al., 2013
GA_3	75 ppm	Maximum fruit count and yield (~1.5 kg/vine vs 0.22 kg control, 6–7× increase); longer and heavier fruits	Pakistan, Faisalabad	Ghani et al., 2013
NAA	100 ppm (4-leaf stage)	Highest fruit set % and yield (~1.75 kg/vine vs 0.19 kg control, ~8× increase); early female flowering	Pakistan, Faisalabad	Ghani et al., 2013
NAA	50 ppm (2-leaf stage)	Shortest interval from flowering to harvest; earlier maturity	Pakistan, Faisalabad	Ghani et al., 2013
Ethrel (ethephon)	500–600 ppm	Promoted femaleness but delayed first flowering (~50–51 days vs 41 control); moderate yield gains	Pakistan, Faisalabad	Ghani et al., 2013
GA_3	30–90 ppm	Improved fruit traits (size, weight, number); 30 ppm induced earlier harvest, 90 ppm raised yield up to 38.8 t/ha	Pakistan, Peshawar field study	Shahet et al., (2022).
GA_3 (general cucurbits)	60 ppm	Increased fruit number and weight	Global review (multi-location cucurbit trials)	Sandra, et al. (2015).
Ethrel (general cucurbits)	50 ppm	Increased fruit set and weight in bitter gourd and related cucurbits	International review	Sandra et al., 2015
GA_3 (sex expression)	—	Promoted femaleness (gynoecy) in bitter gourd, opposite to effect in cucumber	China, physiology study	Wang, R., & Zeng, G. (1996).
NAA & Ethrel (general cucurbits)	50–100 ppm	Increased female flowers and yield in cucurbits (cucumber, pumpkin, bottle gourd)	India, field trials	Singh, A. K., Kumar, S., & Pandey, V. (2012).
Integrated PGRs + 3G Cutting	GA_3 + NAA + Ethrel with pruning	Synergistic effect: more female flowers, improved yield and seed production	India, review study	Debnath, et al., (2023).

It is concluded from the experiment, NAA at 100 ppm applied at the 4-leaf stage is the most powerful treatment for boosting yield and fruit set in bitter gourd, giving nearly an eightfold increase. GA_3 at 25–75 ppm makes plants flower earlier, produces bigger fruits, and increases female flowers — a contrast to cucumber, where it promotes male flowers. Ethrel strongly feminizes vines but delays flowering, making it more useful for seed production than for market yield. International studies from China and India confirm that auxins and ethylene donors push vines toward femaleness, while bitter gourd uniquely shows a GA_3-driven gynoecy effect.

Maize & Sweet Corn (Zea mays L.)

Maize is Pakistan's third most important cereal crop after wheat and rice, cultivated both as field corn and sweet corn. Given its dual role as food and feed, improving cob size, kernel weight, and stress tolerance has become a key focus for researchers, with plant growth regulators (PGRs) offering promising solutions. In a study on sweet corn, Saiin et al. (2020) tested indole-3-butyric acid (IBA, an auxin) and gibberellic acid (GA_3, a gibberellin), applied at two developmental stages: the vegetative stage (6–8 leaves) and the reproductive stage (tasseling/silking). The findings highlighted the critical importance of timing, as PGRs applied at the vegetative stage produced larger cobs and heavier kernels compared to application during the reproductive phase. Specifically, cob weight reached approximately 456 g and kernel weight 455 g with vegetative-stage treatments, whereas reproductive-stage applications yielded slightly improved cob girth but reduced overall grain weight (~445 g per cob). In terms of effectiveness, IBA significantly outperformed GA_3. Application of IBA at 100 mg/L during the vegetative stage increased grain yield to 51.8 t/ha, a 24% improvement over the control, while GA_3 at the same rate and timing resulted in a more modest yield of 45.3 t/ha (an 8–9% gain). These results are explained by the physiological roles of the two regulators: IBA promotes stronger root development and nutrient uptake, thereby supporting larger ears, while GA_3 primarily elongates stems and increases vegetative growth, which, if applied late, can divert resources from grain production and even increase lodging risk. International evidence reinforces these findings. In rice, late GA_3 application at the grain-filling stage reduced both grain weight and milling quality, underscoring the dangers of mistimed gibberellin use (Pan et al., 2013). In wheat, GA_3 seed priming under saline conditions improved grain numbers, but only when timing was carefully managed (Iqbal et al., 2011). Similarly, in maize, triazole regulators such as paclobutrazol (PBZ) have been shown to suppress excessive vegetative growth, enhance root depth, and improve antioxidant activity, thereby enabling drought tolerance in rainfed systems. These insights suggest that for Pakistan's maize production, auxin-based interventions like IBA hold superior potential for yield improvement, while GA_3 and triazoles may serve as context-specific tools for managing stress and growth balance.

Table 4 Maize & Sweet Corn (Zea mays L.) - PGR Comparisons

PGR	Best Dose	Main Outcome	Context	Reference (APA)
IBA (auxin)	100 mg/L (6–8 leaf stage)	Highest grain yield (**51.8 t/ha**; ~24% > control), heavier cobs (456.8 g) & kernels (454.8 g)	Sweet corn hybrid, vegetative application	Saiin et al., 2020
IBA (auxin)	100 mg/L (reproductive stage)	Yield ~51.3 t/ha; still higher than GA_3 but slightly less than vegetative timing	Sweet corn, tasseling/silking	Saiin et al., 2020
GA_3 (gibberellin)	100 mg/L (vegetative stage)	Yield ~45.3 t/ha (≈8–9% > control); taller plants but less kernel gain vs. IBA	Sweet corn hybrid, vegetative	Saiin et al., 2020
GA_3	50 mg/L (vegetative stage)	Yield ~44.1 t/ha; modest improvement in cob girth and kernel rows	Sweet corn hybrid	Saiin et al., 2020
GA_3 (late use caution)	Foliar at grain-filling stage	Decreased 1000-grain weight and rice milling quality → caution for late use in cereals	Rice, China	Pan et al. (2013).
GA_3 (seed priming)	50 mg/L	Improved grain number under salinity by altering ion balance and hormone levels	Wheat under salt stress, Pakistan	Iqbal, et al (2011)
PBZ (paclobutrazol, triazole)	~50 mg/L foliar spray	Shorter plants, deeper roots, improved drought tolerance & water use efficiency	Maize under drought-prone areas (review evidence)	Rademacher, 2015
Nutrient + GA_3	GA_3 + Zn/K/Ca fertilization	Synergistic effect on cob traits and stress tolerance (better than GA_3 alone)	Maize, multi-trial reports	Zhimomi & Dawson (2023) This study found that combining soil-applied zinc (10 kg/ha) with foliar zinc (0.25%) plus GA_3 at 150 ppm produced significantly taller plants, heavier cobs, more kernel rows, and up to **6.76 t/ha grain yield**—a strong synergy between nutrient and PGR use

It is concluded, IBA at around 100 mg/L during vegetative growth is king for maize and sweet corn, boosting yields by nearly 10 t/ha compared to control. GA_3 helps with early ear traits, but later sprays can actually backfire by reducing grain weight, so it's best applied only at the vegetative stage or used as seed priming under stress. PBZ and other triazoles have proven useful in Pakistan's rainfed maize, producing shorter, drought-hardy plants with deeper roots. Combo strategies are also showing promise globally, like pairing GA_3 with nutrients such as zinc or calcium for stronger results.

Tomato (Solanum lycopersicum L.)

Tomato cultivation in Pakistan frequently suffers during the summer season, as high temperatures cause severe flower drop before fruit set, drastically reducing yields. Plant growth regulators (PGRs) have shown potential in mitigating this stress by enhancing fruit initiation and retention under adverse conditions. A key study conducted in Bangladesh by Islam et al. (2013), relevant to Pakistan's growing environment, tested the effects of 4-CPA (a synthetic auxin) and GA_3 (a gibberellin) at concentrations of 20–30 ppm during the flowering stage. The combined application of 4-CPA and GA_3 (20 ppm each) produced the most significant results, nearly doubling fruit numbers per plant (36.5 vs. 18.2 in the control) and boosting yield to 28.4 t/ha compared with 17.4 t/ha in the control—a 63% increase. Plants under this treatment were taller (86 cm compared to ~70 cm), developed more flower clusters (10.6 vs. 6.1), and produced larger fruits (74 g vs. 56 g each). By contrast, single-hormone treatments were less effective: 4-CPA alone increased flower numbers but resulted in poor fruit set, while GA_3 alone provided only modest benefits. The superior effect of the combination reflects their complementary roles: 4-CPA induces parthenocarpy by stimulating ovary development without pollination and prevents heat-induced flower abortion, while GA_3 promotes cell division and expansion in young fruits, supports pollen tube growth, and enhances ovule development. Together, auxin and gibberellin synergistically ensure both fruit initiation and growth, leading to higher yields and improved fruit quality. Additional studies reinforce these findings: NAA (another auxin) at 50 ppm reduced days to first flowering by approximately 12% in tomato, demonstrating auxins' role in accelerating reproductive transitions, while Gemici et al. (2003) reported that combined auxin and GA applications improved tomato yield and fruit quality under high-stress conditions.

Table 5 Tomato - PGR Comparisons

PGR / Mechanism	Best Dose / Details	Main Outcome	Context	Reference (APA)
4-CPA + GA_3	20 ppm each (flowering)	Doubled fruit set (~36.5 vs 18 fruits/plant), ~63% yield boost (28.4 vs 17.4 t/ha), bigger fruits under heat	Bangladesh (Islam et al., 2013)	Islam, et al., (2013).
4-CPA alone	60 ppm (greenhouse)	Highest yield per plant, good fruit quality, barely detectable residue	Turkey greenhouse (98)	Özgüven, et al., (1998).
4-CPA alone	75 ppm field spray	Highest fruit set & yield and great economic benefit under high heat	Botswana, field	Baliyan, et al., (2013).
ARF8 mutation / parthenocarpy	genetic alteration	Stable fruit set under temperature extremes; more fruit-bearing branches; yield stability across climates	Tomato mutants studied in controlled and field trials	Israeli, et al. (2023).
Auxin + GA signallers	Genetic (SlARF5 downregulation)	Induced seedless parthenocarpic fruit set without pollination	Transgenic tomato	Liu, S., et al. (2018).

Auxin response mechanics	Mutated ARF genes	Dis-inhibiting fruit set under heat; parthenocarpy via SlARF8A/B pathways	Tomato molecular biology	Israeli, et al. (2023).

It is concluded from the experiments, for summer tomato, a foliar spray of 4-CPA at 20 ppm combined with GA_3 at 20 ppm should be applied at flowering, with the first spray at initial flowering and a repeat a week later for full coverage. Higher auxin doses should be avoided, as they can lead to oddly shaped fruits. This approach can deliver around a 60% boost in yield with larger, more marketable fruits. Auxins like 4-CPA and NAA are especially critical under heat stress, as they prevent flower drop and can even induce parthenocarpy. GA_3 alone promotes plant growth but is less effective for fruit set compared to auxins, while the combination of auxin and GA_3 provides the best synergy—producing more flowers, more fruits, heavier fruits, and up to 60% higher yield.

Hybrid Rice

Hybrid rice has the potential to yield up to 20% more than conventional varieties, but realizing this advantage depends on careful crop management. Plant growth regulators (PGRs) are particularly important in optimizing hybrid rice performance by enhancing spikelet fertility, prolonging leaf activity, and improving grain filling. A study by Pan et al. (2013) in China, highly relevant for Pakistan's hybrid rice systems, evaluated the effects of gibberellic acid (GA_3), paclobutrazol (PBZ), and 6-benzylaminopurine (6-BA) when applied at the heading stage. PBZ (50 mg/L) produced the most consistent benefits: plants developed more spikelets per panicle, achieved higher seed-set rates, and increased yields by about 13% (from 6.5 to 7.4 t/ha). PBZ also strengthened stems, reduced lodging risk, and improved grain quality by increasing amylose content and lowering the proportion of broken grains. The cytokinin 6-BA (30 mg/L) also proved effective, enhancing grain filling rate, reducing chalkiness, producing more translucent grains, and maintaining green leaves for longer by delaying senescence, ultimately increasing yield by 10–12%. In contrast, GA_3 application at heading lengthened panicles but made plants excessively tall and prone to lodging. It also reduced grain weight and quality, as indicated by increased chalkiness and decreased 1000-grain weight, suggesting GA_3 is more useful in seed production—where panicle emergence is critical—than in grain yield improvement. Mechanistically, PBZ works by inhibiting gibberellin biosynthesis, which keeps plants shorter and sturdier, while redirecting energy toward panicle development and delaying leaf senescence through higher cytokinin and ABA activity. Similarly, 6-BA, as a cytokinin, extends cell activity in developing grains and flag leaves, resulting in improved grain filling and quality. By contrast, GA_3 at heading can be counterproductive for yield and quality.

Supporting evidence from Zheng et al. (2011) and Pan et al. (2013) further confirmed that PBZ, 6-BA, and even NAA sprays improve seed-setting rates, reduce chalkiness, and delay leaf senescence in rice, while GA_3 at the heading stage carries risks for yield stability.

Table 6 Hybrid Rice - PGR Comparisons

PGR	Best Dose	Main Outcome	Context	Reference (APA)
PBZ (Paclobutrazol)	50 mg/L (heading stage)	↑ Spikelets per panicle, ↑ seed-set %, delayed senescence, stronger stems, reduced lodging; yield ↑ ~13% (6.5 → 7.4 t/ha); higher amylose & milling quality	Super hybrid rice, China	Pan et al., 2013
6-BA (Cytokinin)	30 mg/L (heading stage)	↑ Grain filling, ↓ chalkiness, greener leaves (delayed senescence); yield ↑ 10–12%	Hybrid rice, China	Pan et al., 2013
GA_3 (Gibberellin)	20–30 mg/L (heading stage)	↑ Panicle length, slight ↑ spikelets, but risk of lodging; ↓ grain weight & quality (chalkiness ↑, 1000-grain weight ↓)	Super hybrid rice, China	Pan et al., 2013
PBZ, 6-BA, NAA	PBZ 50 mg/L; 6-BA 30 mg/L; NAA-Na 20–30 mg/L	Delayed flag leaf senescence, ↑ seed-setting rate, improved grain filling and quality	Rice cultivars, China	Zheng, et al., (2011).
PBZ (drought stress)	25–50 mg/L (soil/foliar)	Improved tillering, panicle number, grain yield, and water use efficiency under drought	Rice, Philippines	Azarcon, et al., (2022).
PBZ (stress resilience)	~50 mg/L	Improved photosynthesis, antioxidant activity, delayed senescence; ↑ drought tolerance	Rice, multi-location studies	Maheshwari, C. (2024).
6-BA (heat stress)	20–30 mg/L (heading stage)	Boosted spikelet fertility, grain number, and grain weight under heat; delayed senescence	Rice, China	Wu, C., et al. (2016).
Cytokinin review evidence	6-BA, CK precursors	Enhanced yield & stress tolerance in cereals by keeping leaves green & active longer	Rice and other cereals, review	Panozzo, et al., (2025).

It is concluded from the experiments, PBZ at 50 mg/L is the best treatment for combining yield and quality in rice, as it produces more spikelets, stronger stems, delayed senescence, and better milling quality; under drought stress, it also boosts tillering, water use efficiency, and antioxidant activity. 6-BA at 30 mg/L performs almost as well as PBZ for yield, but it stands out for grain quality by reducing chalkiness and producing more translucent grains; under heat stress, it further improves spikelet fertility and grain filling. GA_3 at 20–30 mg/L is mainly useful for seed production because it promotes panicle exertion, but it does not improve grain yield and, if mistimed, can reduce 1000-grain weight, increase chalkiness, and raise the risk of lodging. Overall, for hybrid rice in Pakistan, PBZ or 6-BA sprays at heading can add 10–15% yield along with better grain quality, with PBZ being the best fit for drought-prone regions and 6-BA proving ideal in heat-stressed environments.

Wheat (Triticum aestivum L.)

Wheat is the staple crop of Pakistan, yet its yields have remained stagnant despite improvements in fertilizer use and breeding. Plant growth regulators (PGRs) are emerging as a promising approach to overcome this limitation by enhancing stress tolerance, improving reproductive traits, and sustaining grain filling. Ahmad et al. (2022) demonstrated that nitrophenolate-based PGRs (sodium 5-nitroguaiacolate, sodium ortho-nitrophenolate, and sodium para-nitrophenolate, commonly sold as Atonik) significantly improved wheat performance when applied as foliar sprays during the tillering and booting stages. The 150 ppm treatment was particularly effective, increasing plant height (109 cm vs. 97 cm in the control), tiller number (41 vs. 30 per five plants), spike length (17–18 cm vs. 13 cm), and grain number per spike (64 vs. 50). Yield gains reached 31% in the first year and 53% in the second year, with the optimum dose being 100–150 ppm, as higher concentrations slightly reduced performance. The mechanism behind these results lies in nitrophenolates acting as antioxidants, protecting leaves from oxidative stress, delaying senescence, and prolonging photosynthetic activity, which allows for longer grain filling and heavier kernels. These benefits were achieved at a remarkably low cost (~PKR 80 per acre), providing farmers with additional income of PKR 10,000–15,000 per acre. Supporting evidence from earlier studies in Pakistan further highlights the role of PGRs in wheat improvement under both normal and stress conditions. Arfan et al. (2007) reported that a 0.5 mM foliar spray of salicylic acid enhanced photosynthesis, expanded leaf area, and improved biomass under salt stress, while Iqbal et al. (2011) showed that gibberellic acid (GA_3) seed priming at 50–100 ppm improved seedling vigor, root and shoot growth, and increased grain yield by about 15% under both normal and saline environments. Collectively, these studies confirm that PGRs such as nitrophenolates, salicylic acid, and GA_3 represent cost-effective and practical tools to enhance wheat yield potential and resilience in Pakistan's challenging agro-climatic conditions.

Table 7 Wheat - PGR Comparisons

PGR	Best Dose	Main Outcome	Context	Reference (APA)
Nitrophenolate mix (sodium 5-nitroguaiacolate, sodium ortho-nitrophenolate, sodium para-nitrophenolate)	100–150 ppm (foliar, tillering & booting)	↑ Plant height, tillers, spike length, grains per spike, biomass & yield (+25–53%)	Field/pot trials, Lahore (Pakistan)	Ahmad, et al., (2022).
Salicylic acid	0.5 mM foliar spray	Improved photosynthesis, leaf area & biomass under salt stress	Salt stress conditions, Pakistan	Arfan, et al., (2007).
GA_3 (Gibberellic acid) seed priming	50–100 ppm (seed soak)	↑ Seedling vigor, root/shoot growth, grain yield (~15%)	Normal & saline conditions, Faisalabad (Pakistan)	Iqbal, et al., (2011).
PBZ (Paclobutrazol, triazole)	~50 mg L^{-1} foliar (review evidence)	Shorter plants, deeper roots, improved drought tolerance & water-use efficiency	Drought-prone wheat regions (review/global)	Rademacher, W. (2015).
Brassinosteroids	0.1 ppm foliar spray	Boosted photosynthesis, antioxidant activity, yield ↑ 12–20%	Wheat under heat stress, China	Wang, Z., et al., (2019).
CCC (Chlormequat chloride, anti-gibberellin)	200–300 ppm foliar spray	Reduced plant height, ↑ spike density, ↓ lodging, yield ↑ 8–12%	Irrigated wheat fields, Iran	Shekoofa, A., & Emam, Y. (2008).
Mepiquat chloride	150–200 ppm foliar spray	Reduced stem height, improved grain filling, yield ↑ 10–15%	Multan (Pakistan) irrigated wheat	Naeem, et al., (2012).

It is concluded from the experiments, in wheat, nitrophenolates (100–150 ppm) give the strongest yield boost (25–50%), while other PGRs (GA_3, PBZ, brassinosteroids, CCC, mepiquat chloride) fine-tune growth for stress tolerance, early vigor, or lodging control.

Conclusion:

In conclusion, plant growth regulators (PGRs) act as powerful tools to enhance crop productivity when applied at the correct stage and in appropriate concentrations. Auxins such as NAA and 4-CPA have proven effective in crops like chili, bitter gourd, and tomato by preventing flower drop and improving fruit set, leading to substantial yield increases. Gibberellins (GA_3) can accelerate growth and flowering, but their benefits depend on careful timing and dosage, as excessive use often results in tall, weak plants and reduced grain weight. Cytokinins such as 6-BA delay leaf senescence, thereby extending photosynthetic activity and improving grain filling in cereals like rice. Growth retardants such as paclobutrazol (PBZ) strengthen plant architecture by reducing excessive height and preventing lodging, while nitrophenolates act as broad-spectrum enhancers of vigor, tillering, and grain filling, particularly in wheat. Collectively, these studies indicate that PGRs can increase yields by 20–50% when integrated with sound agronomic practices. However, misapplication—whether through overdosing or poor timing—can negate their benefits. Thus, PGRs should be viewed not as substitutes for fertilizers or breeding, but as complementary technologies that, when used judiciously, offer a cost-effective pathway toward higher yields, improved crop resilience, and greater food security in Pakistan.

Recommendations

Based on the available evidence, Pakistan can unlock the full potential of plant growth regulators (PGRs) by adopting a comprehensive, multi-tiered strategy that combines farmer capacity building, scientific precision, and policy support. Farmers must be equipped with proper awareness and hands-on training regarding crop-specific PGRs, safe concentrations, and correct timing of application through agricultural universities and extension services, minimizing the risks of misuse. To maximize efficiency, standardized crop-wise guidelines should be developed for major staples and vegetables such as wheat, rice, maize, chili, bitter gourd, and tomato, specifying the most effective PGR type, dosage and growth stage for use. Importantly, PGRs should be integrated with existing agronomic practices—including balanced fertilization, improved seed varieties, and modern irrigation methods—so they serve as complementary tools within a holistic crop management framework rather than isolated solutions. Local production of PGR formulations must be encouraged to cut costs and ensure smallholder farmers can access affordable, quality products. At the same time, continuous research and large-scale field trials across Pakistan's diverse agro-climatic zones are critical to adapt recommendations for drought, salinity, and heat-stressed environments, refining context-specific protocols. Government intervention will be key: policies should incentivize PGR adoption through subsidies, demonstration plots, and inclusion in national agricultural development programs, while also ensuring strict monitoring and regulation of product quality to prevent misuse or environmental harm. Taken together, these steps can help Pakistani agriculture harness PGRs as powerful allies for boosting yield, resilience, and crop quality in a sustainable manner.

References

Ahmad, M., Khan, M. I., Rafiq, M., Javed, A., & Ali, Q. (2022). Effect of nitrophenolate foliar spray on growth and yield attributes of wheat (*Triticum aestivum* L.). *Pakistan Journal of Agricultural Research, 35*(1), 152–160.

Ahmed, I. H. M., Ali, E. F., Gad, A. A., Bardisi, A., El-Tahan, A. M., Abd-Esadek, O. A., El-Saadony, M. T., & Gendy, A. S. (2022). Impact of plant growth regulators spray on fruit quantity and quality of pepper (*Capsicum annuum* L.) cultivars grown under plastic tunnels. *Saudi Journal of Biological Sciences, 29*(4), 2291–2298.

Alam, M. S., Rahman, M. M., & Sultana, R. (2021). Influence of plant growth regulators on fruit set and quality of chili (Capsicum annuum L.). *Bangladesh Journal of Agricultural Research, 46*(2), 123–134.

Ali, A., Hussain, M., & Khan, S. (2018). Mitigating blossom drop in tomato through gibberellic acid and auxin applications under high temperature. *Pakistan Journal of Agricultural Sciences, 55*(2), 275–283.

Ali, M., Zafar, S., & Mehmood, T. (2020). Role of nitrophenolates in enhancing crop productivity under stress conditions. *Journal of Agricultural Research, 58*(1), 45–55.

Anjum, M. A., Hussain, S., & Shakeel, F. (2017). Impact of NAA on fruit retention and quality in chili (Capsicum annuum L.). *International Journal of Agriculture and Biology, 19*(5), 1101–1108.

Arfan, M., Athar, H. U. R., & Ashraf, M. (2007). Does exogenous application of salicylic acid through the rooting medium modulate growth and photosynthetic capacity in two differently adapted spring wheat cultivars under salt stress? *Journal of Plant Physiology, 164*(6), 685–694.

Azarcon, R. P., Vizmonte, P. T., Jr., & Agustin, A. M. L. (2022). Effect of Paclobutrazol on the yield and yield components of transplanted rice under drought stress. *Mindanao Journal of Science and Technology, 20*(1), 38–60.

Baliyan, S. P., Baliyan, P. S., Rao, K. S. M., & Mahabile, M. (2013). The effects of 4-chlorophenoxyacetic acid plant growth regulator on the fruit set, yield and economic benefit of growing tomatoes in high temperatures. *International Journal of Agricultural Science and Research, 3*(2), 29–36.

Chaudhary, B. R., Sharma, M. D., Shakya, S. M., & Gautam, D. M. (2006). Effect of plant growth regulators on growth, yield and quality of chilli (*Capsicum annuum* L.) at Rampur, Chitwan. *Journal of the Institute of Agriculture and Animal Science, 27*, 65–68.

Davies, P. J. (2010). *Plant hormones: Biosynthesis, signal transduction, action!* (3rd ed.). Springer.

Debnath, A., Haldar, A., & Mukherjee, P. K. (2023). Application of different plant growth regulators (PGRs) on yield and quality of bitter gourd: A review. *The Pharma Innovation Journal, SP-12*(11), 864–867.

Dey, P., Chattopadhyay, A., & Bera, P. (2022). Effect of NAA on growth and yield of chili (Capsicum annuum L.) in West Bengal. *Indian Journal of Horticulture, 79*(1), 45–51.

Fletcher, R. A., Gilley, A., Sankhla, N., & Davis, T. D. (2000). Triazoles as plant growth regulators and stress protectants. *Horticultural Reviews, 24*, 55–138.

Gemici, M., Türkyılmaz, B., & Aydin, M. (2003). Effects of growth regulators on fruit set, yield, and quality of tomato (*Lycopersicon esculentum* Mill.). *Acta Horticulturae, 613*, 231–238.

Gemici, M., Türkyılmaz, B., & Aydin, M. (2003). Effects of growth regulators on fruit set, yield, and quality of tomato (*Lycopersicon esculentum* Mill.). *Acta Horticulturae, 613,* 231–238.

Ghani, A., Anjum, M. A., Hussain, S., Ahmad, R., & Ali, M. A. (2013). Influence of plant growth regulators on sex expression and yield of bitter gourd (*Momordica charantia* L.). *International Journal of Agriculture and Biology, 15*(2), 249–256.

Habib, M., Qureshi, R. H., & Aziz, T. (2014). Cytokinins in relation to senescence and yield improvement. *Journal of Plant Growth Regulation, 33*(3), 473–485.

Hafez, E. M., et al. (2020). Impact of gibberellic acid and plant growth regulators on chili under plastic tunnel conditions. *Scientia Horticulturae, 261*, 108939.

Hussain, M., Khan, M. B., & Farooq, M. (2021). Foliar application of growth regulators improves grain filling and yield in wheat under drought. *Field Crops Research, 261*, 108018.

Iqbal, M., Ashraf, M., Jamil, A., & Rehman, S. U. (2011). Does seed priming induce changes in the levels of some endogenous plant hormones in hexaploid wheat plants under salt stress? *Journal of Integrative Plant Biology, 53*(11), 961–972.

Islam, M. R., Alam, M. S., & Rahman, M. M. (2016). Regulation of sex expression in cucurbits through plant growth regulators. *Scientia Horticulturae, 203*, 29–36. https://doi.org/10.1016/j.scienta.2016.03.009

Islam, M. T., Saha, S. R., Rahman, M. A., & Islam, M. S. (2013). Effect of plant growth regulators on fruit set and yield of summer tomato (*Lycopersicon esculentum* Mill.). *Bangladesh Journal of Agricultural Research, 38*(2), 279–285.

Israeli A, Schubert R, Man N, Teboul N, Serrani Yarce JC, Rosowski EE, Wu MF, Levy M, Efroni I, Ljung K, Hause B, Reed JW, Ori N. Modulating auxin response stabilizes tomato fruit set. Plant Physiol. 2023 Jul 3;192(3):2336-2355.

Jilani, T. A., Sherani, J., Javaria, S., Waseem, K., Hameed, M. S., Ain, N. U., Zaman, A., & Saddozai, U. K. (2025). Impact of plant growth regulators on the growth and yield characteristics of chili (*Capsicum annuum* L.). *Sarhad Journal of Agriculture, 41*(2), 764–769.

Khan, N. (Ed.). (2021). *Application of plant growth promoting microorganism and plant growth regulators in agricultural production and research*. MDPI.

Liu, S., Zhang, Y., Feng, Q., Qin, L., Pan, C., Lamin-Samu, A. T., & Lu, G. (2018). Tomato AUXIN RESPONSE FACTOR 5 regulates fruit set and development via mediation of auxin and gibberellin signaling. *Scientific Reports, 8*, Article No. 2971.

Maheshwari, C. (2024). Ameliorative effects of paclobutrazol via physiological adjustments under water deficit in rice. *BMC Plant Biology*, *24*(1), 153.

Naeem, M., Iqbal, J., Cheema, Z. A., & Anjum, S. A. (2012). Effect of mepiquat chloride on growth, lodging and yield of wheat (*Triticum aestivum* L.). *International Journal of Agriculture & Biology*, *14*(5), 915–920.

Özgüven, A. I., Paksoy, M., & Abak, K. (1998). The effects of 4-CPA in greenhouse tomato on fruit set, quality and residue. *Acta Horticulturae, 463*, 243–250.

Pan, J., Li, Z., Dai, L., Habibullah, N., Zhang, L., & Chen, J. (2013). Effects of spraying gibberellic acid at grain-filling stage on rice yield and quality. *Field Crops Research, 146,* 1–7.

Panozzo, A., Bolla, P. K., Barion, G., Botton, A., & Vamerali, T. (2025). Phytohormonal regulation of abiotic stress tolerance, leaf senescence, and yield response in field crops: A review. *Frontiers in Plant Science, 16*, 1487.

Rademacher, W. (2015). Plant growth regulators: Backgrounds and uses in plant production. *Journal of Plant Growth Regulation*, *34*(4), 845–872.

Ramírez-Rivera, R., et al. (2021). Effects of gibberellic acid and fertilization on jalapeño yield and quality. *Revista Mexicana de Ciencias Agrícolas, 12*(6), 1151–1162.

Sadasivam, S., & Manickam, A. (2019). *Biochemical methods* (4th ed.). New Age International Publishers.

Saiin, A., Laohakunjit, N., & Kerdchoechuen, O. (2020). Effects of indole-3-butyric acid and gibberellic acid on growth and yield of sweet corn (*Zea mays* L. var. saccharata). *Journal of Crop Science and Biotechnology*, *23*(2), 171–182.

Sandra, J., Paul, M., & Verma, R. (2015). Effect of plant growth regulators on fruit set, yield, and quality of bitter gourd (*Momordica charantia* L.): A review. *International Journal of Ecology and Climate Change, 5*(3), 45–53.

Serrani, J. C., Fos, M., Atarés, A., & García-Martínez, J. L. (2007). Effect of gibberellin and auxin on fruit set and development in sweet pepper. *Physiologia Plantarum, 130*(4), 593–604.

Shah, A. N., Tanveer, M., & Abbas, M. (2019). Role of plant growth regulators in lodging resistance in cereals. *Cereal Research Communications*, *47*(4), 617–628.

Shahniza Saiin, S., Ismail, M. F., & Ismail, R. (2020). Effect of time of application and concentrations of plant growth regulators on growth and yield of sweet corn (*Zea mays* L.). *Research on Crops, 21*(1), 34–40.

Shekoofa, A., & Emam, Y. (2008). Effects of plant growth regulators on lodging, yield, and yield components of wheat (*Triticum aestivum* L.) at different plant densities. *Asian Journal of Plant Sciences*, *7*(4), 355–360.

Singh, A. K., Kumar, S., & Pandey, V. (2012). Effect of NAA and ethrel on sex expression and yield of cucurbits. *Vegetable Science, 39*(1), 35–39.

Taiz, L., Zeiger, E., Møller, I. M., & Murphy, A. (2015). *Plant physiology and development* (6th ed.). Sinauer Associates.

Wang, R., & Zeng, G. (1996). Effect of gibberellic acid and NAA on sex expression in bitter gourd (*Momordica charantia* L.). *Acta Horticulturae Sinica, 23*(4), 433–438.

Wang, Z., Yuan, Y., Ou, J., Zhang, J., & Li, J. (2019). Foliar application of brassinosteroids improves photosynthetic characteristics and grain yield of wheat under heat stress. *Field Crops Research*, *231*, 1–9.

Wu, C., Cui, K., Wang, W., Li, Q., Fahad, S., Hu, Q., Huang, J., & Nie, L. (2016). Heat-induced phytohormone changes are associated with rice yield components. *Scientific Reports, 6,* 34978.

Zafar, S., Ali, M., & Khan, R. (2019). Effect of nitrophenolate-based biostimulants on yield and quality of wheat. *Pakistan Journal of Botany, 51*(3), 1035–1042.

Zheng, H., Dong, H., & Chen, L. (2011). Effects of exogenous plant growth regulators on grain filling and quality in rice (*Oryza sativa* L.). *Plant Growth Regulation, 65*(3), 327–335.

Zhimomi, K. H., & Dawson, J. (2023). Influence of zinc and gibberellic acid on growth and yield of maize (*Zea mays* L.). *International Journal of Plant & Soil Science, 35*(10), 42–51.