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Saljuna KP
ICAR-Indian Institute of Spices Research, Kozhikode

Thankamani CK
ICAR-Indian institute of Spices Research, Kozhikode

Gayathri Pavithran
ICAR-Indian institute of Spices Research, Kozhikode

Corresponding Author:
Saljuna KP
ICAR-Indian institute of Spices Research, Kozhikode

Application of growth regulators in Ginger and turmeric: A review

Saljuna KP, Thankamani CK and Gayathri Pavithran

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Abstract
Plant growth regulators had a potential impact on the agriculture sector, due to its immediate effect on the crop and less time consuming. When administered at lower quantities itself, a bio-regulator can stimulate, inhibits, or changes plant morphological and physiological processes. In present scenario of pursued population growth and limited land availability utilization of plant growth regulators would sustain plant productivity and quality. The major constrain in the field of production of ginger include low production of quality rhizomes. These paper reviews the research work done on the ginger and turmeric using various growth regulators to respond to current needs of enhancing yield in market and drive further growth in ginger and turmeric industry.

Keywords: Ginger, Turmeric, plant growth regulators, tissue culture, yield

Introduction

Ginger (*Zingiber officinale* Rosc.), a member of the Zingerberaceae family, is a well-known commercial spice valued for its aroma, flavor, and pungency. It is a significant source of essential oils, and the direct usage of rhizomes for culinary purposes is growing in popularity around the world. Ginger is mostly used in food as a spice and flavouring component. The volatile oils that give ginger its distinctive scent and flavor are mostly made up of zingerone, shogaols, and gingerols, with zingerone being the most pungent molecule. Ginger also contains starch (50%), protein, (9%) lipids (including glycerides, phosphatidic acid, lecithins, and fatty acids 6-8%) protease (2.26%), volatile oils (including gingerol, shogoal, zingiberene, and zingiberol 1-3%) vitamins A and B_3 (niacin) Murray *et al.*, 1995 [1]. It has a long history of usage as a herbal medicine, dating back to its origins in Southeast Asia and expanded to Europe a variety of symptoms, such as vomiting, discomfort, indigestion, and cold-related syndromes. Ginger has long been regarded as essential in the culinary arts for flavouring dishes. A variety of alcoholic beverages, including brandy, wine, and beer, are made in other countries. Ginger oil is also used in fragrance, medicines, and industrial applications Pruthi *et al.*, 1998 [2]. The use of ginger in various forms is on the rise these days, resulting in an increase in demand all across the world. In the global context, India is the leading producer, consumer, and exporter of ginger and its derivatives. In India, ginger was grown on 210016 hectares with a production of 2503325 tonnes in the years 2022-2023 (Spice India). Despite the importance of the crop, low productivity of the quality rhizomes is one of the major concerns in ginger cultivation. As a solution to constrain in the field of cultivation of ginger, the plant growth regulators application in different concentrations can alter the growth and enhance the productivity of ginger.

Turmeric (*Curcuma longa*) is an ancient spice recognized mainly for its medicinal, scientific, and for also for its culinary purpose. According to Wu, 2015 [3] turmeric is a rhizomatous herbaceous perennial plant of ginger family grown in a warm climate. The plant part used mainly is the rhizomes that contain the bioactive non- volatile compound, called curcumin Itokawa *et al.*, 2008 Lobo *et al.*, 2009 [4, 5]. Turmeric contains the main active constituent curcumin has a wide range of biological activities including antioxidant, anti-inflammatory, antimutagenic, anti-carcinogenic and anti-angiogenic properties Kunnumakkara *et al.*, 2017 [6]. Over 2500 years ago, turmeric had been used as a dye and also a traditional medicine in India, Pakistan and Bangladesh for many condition Bhowmik *et al.*, 2011 [7]. Recently turmeric is being used largely in food as well as non-food items and export demand is increasing Ray *et al.*, 2016 [8]. Curcumin can help in the management of oxidative and inflammatory conditions, arthritis, metabolic syndrome, anxiety, muscle soreness, and hyperlipidemia. Curcumin (1, 7-bis(4-hydroxy-3-methoxyphenyl)-1, 6-heptadiene-3, 5-dione), also called diferuloylmethane, is the main natural polyphenol found in the rhizome of *Curcuma longa* (turmeric) and in others Curcuma spp. Curcumin can help in the management of oxidative and inflammatory conditions, arthritis, metabolic syndrome, anxiety, muscle soreness, and hyper lipidemia Hewlings and Kalman 2017 [9]. The germination rate of the turmeric rhizomes is very less and shows slow initial growth. The use of different plant growth regulators can have an effect on the production and quality of rhizome.

Plant growth regulators (PGR) are organic, natural or synthetic compounds that applied exogenously in smaller quantities and can affect the physiological and morphological process of the plant remote from the place of production, thereby enhances the productivity of crop. Plant growth regulators are a quick means of increasing production and can be applied in form of liquid, powder, paste etc. In plant growth regulators treated plants, and they affect the endogenous balance of plant hormones by their biosynthesis or translocation or by blocking hormone receptors. PGRs used in the field of agriculture, horticulture and viticulture for improving the morphology, harvesting facilitation quantitative and qualitative increase in yield and modifying the plant constituents Rademacher, 2016 [10]. Use of plant growth regulators on ginger and turmeric has been reviewed and presented here.

Plant growth regulators and their types

Plant growth regulators defined as naturally occurring or synthetic compounds mostly exist in low dosages that affect developmental or metabolic process in higher plants Rademacher, 2015 [11]. The term 'hormone' derived from a Greek word 'hormao' means 'to stimulate'. Thimman 1948 [12] coined the term phytohormones as it derived from the plant origin. Plant growth regulators fall under mainly two categories growth retardants and growth promoters. Auxin, Gibberellin and Cytokinin are growth promoters and Ethylene and Abissicisic acid are growth retardants. The biosynthesis of plant hormones is not localized but often diffuse within the plant tissues. The quantity of plant hormones needed for the plants ranges only in minute amounts (10^{-6} to 10^{-5} mol/L). The plant growth hormones act in a different place apart from the site of production and the movement occur in four different types; Cytoplasmic streaming for cell to cell movement, through the vascular tissues for movement from one part of plant to another, through translocation and they they control or modifies different physiological processes Mundiyara *et al.*, 2020 [13].

Classification of plant growth regulators

Plant growth promoters

1. **Auxin:** Auxin are the first growth hormone to be discovered. Auxins are mainly involved in the stem elongation process. They are synthesized in the shoot and root apices and they travels from the apices to the zone of elongation and also in the developing seeds and buds. The promotion of growth along the longitudinal axis and hence the name (Auxeing: to grow or to increase). The auxin was discovered by Charles Darwin and Francis Darwin. The term was introduced by Kogl and Haagen-Smit [14]. In 1926 and 1928, Went isolated auxin from the coleoptile tips by the method of *Avena coleoptile or curvature test*. They are mainly produced in the darker sides of the plant and causing the plant to bend towards the light portion, causing the phenomenon of phototropism. Auxin also promote stem elongation and maintains the apical dominance. The only naturally occurring auxin of all higher plants and fungi are Indole Acetic Acid (IAA) and derived from the Tryptophan, an amino acid. Indole-3-acetic acid (IAA) and Indole butyric acid (IBA) are natural auxins and Naphthalene acetic acid (NAA), 2, 4-dichlorophenoxyacetic (2, 4-D), Phenyiacetic acid (PAA) 2, 4, 5-trichlorophenoxyacetic acid (2, 4, 5-T) Picloram, Dicamba are the synthetic auxins. The auxin stimulates the growth in lower concentrations and at higher concentrations they can retard the growth. Other than stem elongation they can promote flowering, helps to initiate the rooting in stem cuttings, prevent the early droppings and promote natural detachment etc. In the agricultural purpose, they are mainly used for plant propagation, as a herbicide to kill dicotyledon weeds and also induce parthenocarpy.
2. **Gibberellin:** One of the major regulators of plant growth and development that can repress the growth and promoting the cell division and elongation Tomas, 2009 [15]. The discovery of the gibberellin was in early part of twentieth century, when Kurosawa noticed some plants in rice filed with taller, thinner and paler than the normal ones and concluded that it was a disease due to a substance secreted by a parasitic fungi called as *Gibberella fujikuroi.* The disease was named as 'bakanae' means foolish seedlings. Yabuta and Hayashi, 1939 [16] isolated the growth promoting substance in crystalline form and named as gibberellin A. Presently there are 112 types of gibberellins from a variety of organisms from fungi to higher organisms. They are named as GA1, GA2, GA3 etc. among the ones the most studied one is the GA3. The biosynthesis of gibberellin occurs in the young leaves (major site), shoot tip, root tip and immature seeds (embryo) and the precursor of gibberellin is Kaurene. The physiological effects of gibberellins include stem elongation, flower intiation, seed germination, leaf expansion, breaks dormancy, prevent dwarfism, delay senescence etc. In tissue culture, they induce organogenesis mainly adventitious root formation.
3. **Cytokinin:** The major role of the cytokinin is cell division. In 1963, Letham [17] proposed the term Cytokinin and naturally occurring cytokinin was initially found in corn and referred as Kinetin. Cytokinin is mainly synthesized in the root tips. The activity and type of cytokinins differ between the species and tissues, at different developmental stages and under various environmental conditions. Other functions of Cytokinins involve stimulation of organ formation, overcome apical dominance, break dormancy, and enhance seed germination, uniform flowering, and transportation of metabolites in the phloem and also in the preservation of the flowers, fruits and leafy vegetables. Cytokinins functional activity occurs in the presence of auxin.

Plant growth retardants

4. **Ethylene:** Ethylene is the gaseous hormone present in small quantities. Major function of ethylene includes the ripening of fruits and called as ripening hormone. The sensitivity and the synthesis get increased at certain stages of plant development and also by biotic and abiotuc stresses Mikal,

1999 [18]. The effects of ethylene on growth and development depends on the ABA, cytokinin and auxin concentration, light, carbon dioxide and the plant George *et al.*, 2008 [19]. Ethylene can also promote growth by increasing the tolerance to diverse stress conditions.

5. **Abscisic acid:** Absicissic acid is the hormone that is usually associated with the stress response. Multiple physiological processes of plants, such as stomatal closure, cuticular wax accumulation, leaf senescence, bud dormancy, seed germination, osmotic regulation, and growth inhibition among many others are controlled by the presence of the hormone Chen *et al.*, 2020 [20].

Utilization of plant growth regulators in tissue culture of ginger

Slow multiplication, limited availability of high yielding genotypes and susceptibility to rot diseases demanded the application of tissue culture techniques Shaik *et al.*, 2014 [21] reported that with 2.5 mg/l BAP and 1 gm/l NAA added, MS basal medium exhibited the maximum rate of shoot multiplication in ginger. The plant growth regulators such as GA, NAA or kinetin showed a significant effect on the plant growth and rhizome size reported by Gawande *et al.*, 2021 [22] in turmeric. GA 200 ppm treated found superior in plant height and leaf area, CCC 500ppm showed maximum tillers and maximum number of leaves/plant. Interaction of BAP and NAA produced high number of shoots in Ginger by Mosie *et al.*, 2019 [23]. Disease free plants were propagated in vitro with MS medium supplemented with 1.0 mg/l BA and 0.1 mg/l NAA for shoot differentiation in Ginger by Manisha *et al.*, 2018 [24]. Medium supplemented with BA and NAA obtained multiple shoots in ginger from the studies of Gupta *et al.*, 2011 [25]. Highest shoot regeneration rate (4.25) was reported in Benzyl adenine purine (BAP) by Kanu Nkere, 2010 [26]. In clonal propagation of ginger and turmeric BAP alone showed better shoot multiplication than combination of BAP and Kinetin Balachandran *et al.*, 1990 [27]. In most cases, the BAP treatments towards the herbaceous plants are highly responsible to BAP treatments to produce shoots that can be used for the further proliferation of the shoots Debergh and Zimmerman 1991 [28]. Inden *et al.*, 1988 [29] reported that high concentrations of growth regulators can reduce shoot elongation, reduced rooting and caused genetic instability in ginger. Amgai *et al.*, 2017 [30] reported the influence of sucrose in the rhizome weight and the also the addition of NAA in ginger micropropagation. i.e; MS basal media with 60 g/L sucrose+5 mg/L BA+0.5 mg/L NAA had more rhizome weight compared to other lower levels of sucrose. Inderiati *et al.*, 2023 [31] reported that different concentrations of sucrose and growth regulators in red ginger and white ginger and standardized the MS medium with 30 g.l-1sucrose and 1.0 mg.l-1 BA as the optimal medium. After six weeks of culture, it was discovered that shoot tip explants on 2 mgl-1BA and 1 mgl-1 kinetin produced an average of 7 shoots per explant, outperforming other explant-media combinations. As a result, in just four weeks of cultivation, the plantlets grew an average of 8.75 roots, and they thrived in the field and during acclimatization Ayenew *et al.*, 2012 [32]. Shoot multiplication was most efficient in low levels of BAP and rooting was found better in control plants without any plant growth regulators in *Etlingera elatior* torch Ginger Yunus *et al.*, 2012 [33].

MS basal medium supplemented with 2.5 mg/l BAP + 1 gm/l NAA showed the highest rate of shoot multiplication in ginger explants Shaik, 2018 [34]. The shoot multiplication was high in MS basal medium with 2.0 mg/l BAP + 0.5gm/l NAA Kambasaka *et al.*, 2009 [35]. According to the study of Arif *et al.*, 2021 [36] the influence of growth retardant (Chlorocholine chloride) and nutrient level showed a better growth, yield as well as quality traits was reported in ginger. The best medium for shoot multiplication was Murashige and Skoog (MS) supplemented with 10 µM of zeatin, which produced the greatest number of shoots per explant (4.28). Roots per plantlet were greatest in MS media supplemented with 7.5 µM 1-naphthaleneacetic acid (NAA) in Bentong Ginger. Triacontanol at a concentration of 10 ^{6} M considered to be suitable for augmenting the neutraceuticals production and quality of rhizomes of Ginger (2012). Highest gingerol content was seen in ginger shoot cultures in MS medium containing 2 mg L–1 BAP Erika *et al.*, 2016 [37]. For the high frequency production of micro rhizome in *Zingiber officinale* var. Baishey and Nadia, Singh *et al.*, 2014 [38] developed an medium with plant regulators ie., MS medium supplemented with 2 mg/l 6-benzyladenine, 1mg/l α-naphthaleneacetic acid and 8g/l sucrose with 11 µM silver nitrate. Zuraida, 2013 [39] developed a medium with different concentrations and combinations of auxin and cytokinin for effective shoot multiplication and root induction. 3mg/l Benzyl adenine purine (BAP) and 0.5 mg/L NAA (Naphthalene acetic acid) developed highest number of shoots in ginger var. *Rubrum*.

Utilization of Plant Growth Regulators in Tissue Culture of Turmeric

For the rapid multiplication of turmeric (micro propagation) Taghavi *et al.*, 2021 [40] optimized a culture media with plant growth regulator using higher BAP (Benzyl adenine Purine) to NAA (Naphthalena acetic acid) 2.5 mg/L BAP and 0.1 mg/L NAA for shoot proliferation. The dormancy break down in seedlings of turmeric was done using PGR, BAP (benzyl amino purine) and NAA (Naphthalene Acetic Acid) at different concentrations but PGR s did not showed any significant effect on the diameter, number of shoots and number of budding rhizomes Adi *et al.*, 2015 [41]. Since the turmeric shows an low rate of emergence the influence of the growth regulators such as NAA (40 ppm), GA3 (50 ppm), Kinetin (30 ppm) along with different planting materials such as mother rhizome, primary rhizome and secondary rhizome and the maximum emergence was shown by 30 DAP, NAA (40 ppm) Walia *et al.*, 2016 [42]. For the mass production of *Curcuma longa* L. Cv. Roma, Beura *et al.*, 2017 [43] developed MS media supplemented with BAP (3.0 mg/l), NAA (0.2 mg/l) and GA3 (0.2 mg/l) that would produce longer bud up to 0.7 cm. Rahayu *et al.*, 2012 [44] showed that 5 mg/l BAP was the best media for all growth components of Java turmeric in terms of number of shoots, height, number of roots and number of leaves. In experiment with different concentrations of Benzyl adenine (BA) (1.0, 2.0, 3.0 and 4.0 mg/L) and IBA (1.0, 2.0, 3.0 and 4.0 mg/L) either alone or in combination for shoot and root regeneration. Shoot induction was highest percentage (81.00%) was recorded with BA 2.0 mg/L Anik *et al.*, 2018 [45]. Bandara *et al.*, 2021 [46] found that the best plant growth regulator for shoot initiation include BAP (6-Benzylaminopurine), BA (Benzyl Adenine), Kn (Kinetin) alone or in combination with NAA (Naphthalene Acetic Acid) or IAA (Indole-3-Acetic Acid). Shoot proliferation in turmeric under invitro condition were studied by Ugochukwu *et al.*, 2013 [47] using different concentrations of BAP 3, 4, 5, 6, 7 and 8 mg/l and best proliferation were reported in benzyl adenine at 8.0 mg/L. The findings of Theanphong *et al.*, 2010 [48] demonstrated that the combination of 1.0 mg/L BA and 0.5 mg/L NAA supplemented MS agar medium produced the greatest number of new roots (10 roots/explant), new shoots (1.29 shoots/explant), and the longest shoots.

Role on growth parameters of ginger

The growth parameters generally include the plant height, number of tiller, number of leaves, leaf area, leaf width, leaf length, stem diameter. Maximum plant height and maximum number of pseudo stem were recorded by spraying GA3 at 150ppm and ethrel at 150ppm and maximum number of leaves, maximum leaf length and leaf breadth recorded at Ethrel at 100ppm, GA3 at 150 ppm and Cycocel at 200 ppm respectively. GA3 and ethrel have thus a key role in the improvement of the growth parameter of ginger reported by Sengupta *et al.*, 2008 [49]. Rusmin *et al.*, 2015 [50] revealed that the application of paclobutrazol at 400ppm was the best treatment for increasing the number of tillers, shoots and leaves. Plant growth regulators (PGRs) are thought to be profitable for increasing crop production and quality Kende *et al.*, 1997, Naeem *et al.*, 2010 & Jaleel *et al.*, 2007 [51, 52, 53]. The application of hormones provide an significant effect on the plant height, tiller production, number of leaves and also in the rhizome production. In ginger Jayachandran *et al.*, 1979 [54]. It is considerably more common to use synthetic growth regulators and chemicals to limit leaf growth and improve dry matter partitioning in the rhizome stressed out in ginger Maruthi *et al.* 2003 [55].

One of the growth regulators mainly using in the nurseries and greenhouses are the Cycocel. The Cycocel mainly using for the reduction in the height of the plant. Velayutham *et al.*, 2013 [56] described the role of Cycocel in increasing the number of leaves and number of tiller per plant and the Cycocel shows an anti-gibberellin activity, thereby showing a reduction in the height can bring on the more accumulation of photo assimilates in the rhizome. Singh *et al.*, 2012 [57] used Tricontanol (TRIA), a natural component having a growth enhancing properties, proved that foliar spray of TRIA at 10-6 M are optimum and significantly enhanced the plant height, leaf density, number of tillers per plant in ginger. Bezabih *et al.*, 2017 [58] had reported that the exogenous foliar application of 6-Benzyl amino purine is important for the improvement of shoot characteristics such as number of leaves, leaf and shoot length and the proliferation of the tiller. Leaf area (LA), leaf development rate (LDR), stem elongation rate (SER), vigour index (VI) found to be increased with the foliar application of Cycocel and decreased with GA and ethrel Obasi *et al.*, 2009 [59]. The influence of plant growth regulators on growth of ginger variety Nadia in Gangetic alluvial plains of West Bengal was studied by Pariari *et al.*, 2022 [60] and showed that the GA3 at 150ppm recorded highest plant height, leaf length, length of clump and breadth of clump. Arif *et al.*, *(*2021) [36] reported that the under a protected structure of soil less culture, the growth retardant and the nutrient levels had significant influence in the plant height, number of tillers/clump, number of leaves, leaf and leaf area found maximum in plants sprayed with Chlorocholine chloride (CCC) @ 1000 ppm followed by CCC at 500ppm. Phogat (1987) [61] conducted the experiments with the variety of Rio-de-Janeiro with the treatments of Cycocel (250, 500, 100 and 2000 ppm) and ethrel (50, 100, 200 and 400 ppm.) and the height of the plant were reduced significantly due to the anti- gibberellin activity of the Cycocel and the suppressed the growth of plant but found effective in increasing the tiller production leading to better rhizome production. Obasi and Atanu (2005) [62].conducted a field experiments to study the effect of foliar application of growth regulators on growth, flowering and rhizome yield of ginger. Results revealed that leaf area (LA), leaf development rate (LDR), stem elongation rate (SER), vigour index (VI) and rhizome yield were increased with CCC and decreased with GA3 and ethrel. Application of CCC @ 250 ppm significantly improved rhizome yield by 36.4%.

Application of Paclobutrazol at 400 mg/l had reported the lowest height of torch ginger and the growth retardant activity of the Paclobutrazol inhibited the Kaurene oxidase and thus blocks the synthesis of gibberellic acid Muangkaewngam *et al.*, 2018 [63]. Arif *et al.*, 2022 [36] reported that the anti- gibberellin acitivity of the plant growth regulator Chlorocholine chloride inhibit the cell division and reduction in the stem elongation reduced the plant height of ginger. Physiological parameters also improved by the application of plant growth regulators. Muangkaewngam *et al.*, 2018 [63] reported that the number of chloroplast and the guard cell density in ginger leaves gave the highest in number and highest width and length respectively for the plants treated with the 400mg/l Paclobutrazol. Increased chlorophyll content in leaf was seen in plants applied with paclobutrazol than the control and the increased content of chlorophyll may be due to the biosynthesis of fitol substance concentration by blocking the gibberellin biosynthesis. The application of PBZ, triazole able to enhance cytokinin biosynthesis, an important enzyme that had role in chloroplast differentiate, chlorophyll biosynthesis and prevent chlorophyll from degrading Rusmin *et al.*, 2015 [50]. Barium Sulphate (BA) foliar spray at 75ppm, along with 100 percent NPK, produced maximum ginger characteristics such as height of the plant, number of tiller, etc. in ginger transplanted under Hill zone of Karnataka. (Nayak *et al.*, 2012) [64].

Role on growth parameters of turmeric

Kumar *et al*., (2017) [65] reported an experiment conducted to observe the effect of plant growth regulators Cycocel 1000ppm, 6- BA 5 ppm, NAA 20 ppm. Of these, maximum height and number of tiller was noticed in NAA 20 ppm and other vegetative parameters. Turmeric genotypes such as Amalapuram and Rajapuri were treated with plant growth regulators (CCC [chlormequat] (at 500 and 1000 ppm), Cytozyme (at 1000 and 2000 ppm), Miraculan (at 1000 and 2000 ppm) to see the effects on biochemical, biophysical and quality attributes by Jirali *et al.*, 2008 [66]. Among these the Amalapuram genotype recorded superior characters, with CCC at 1000 ppm (at 60 and 120 days after sowing). Singh *et al*., 2016 [67] found that using mother rhizomes and foliar application of NAA 40 ppm, Kinetin 30ppm is better in emergence count, plant height, leaf area and dry matter accumulation rather than GA 50 ppm. Gawande *et al*., 2012 [22] experimented the influence of the planting material, plant growth regulators and also the rhizome size of turmeric and found that GA 200 ppm with mother rhizome is superior in plant height and leaf area. In the same experiment, number of tillers per plant and number of leaves per plant found to be high in primary rhizome and Cycocel at 500 ppm treated plants. Pujari *et al*., (2016) [68] reported that Turmeric var. Suroma, the plant height, number of leaves per tiller, leaf area, was found to be higher in NAA 20ppm. The plant height, leaf length, leaf width, number of leaves and tillers per plant in variety Gujarati Navsari was obtained highest in NAA@100mg/L Thounaojam *et al*., 2016 [69]. Venugopal *et al.*, 2017 [70] found that foliar spray of GA at 100ppm as effective treatment for the commercial production of turmeric. In order to improve the productivity in turmeric the combined application of Triacontanol and kinetin found be better at an concentration of 10^{-6} M TRIA + 1.0×10^{-5} M KN in most parameters such as plant height, fresh mass, number of leaves, number of tillers per plant (Masroor *et al.*, 2006) [71].

Effect on the yield and yield attributes in ginger

Plant growth regulators had significant effect on the yield of ginger. The improvement in the rhizome production in ginger is reported by the presence of the plant growth regulators. Sengupta *et al.*, 2008 [49] reported that the foliar spray of GA3 at 150ppm recorded maximum rhizome yield. Rusmin *et al.*, (2016) [50] shown a linear increase in the fresh weight of the rhizome and number of rhizome branches up to the application of Paclobutrazol at 400ppm at 4MAP and also shown positive results on the rhizome length, height. The length and the height of the primary, secondary and tertiary rhizomes did not influence by the time of application of the Paclobutrazol, but the thickness of primary finger increased significantly after the application of 200 ppm compared to without the treatment.

The yield characters, number of primary and secondary rhizomes per plant, length and girth of primary and secondary rhizomes, fresh and dry weight of rhizomes, yield per plot and yield per hectare were reported to be higher in CCC 500 ppm foliar sprayed plants. The Cycocel helps in the reduction of plant height and thereby effective in moderating the vegetative growth by mobilizing the photosynthates from other parts to the rhizomes Velayutham *et al.,* 2013 [56]. The yield attributes (number of primary fingers per plant, number of secondary fingers per plant and rhizome yield per plant) were significantly affected by the application of Triacontanol (TRIA) at 10^{-6} than the controls and caused a yield increase of 59.5%. The favorable effect of the TRIA n the quantity of primary and secondary fingers per plant and on rhizome output are caused by enhanced nutrient absorption and photosynthetic speed as well as the movement of photosynthates and other eventually leading to the sinks, metabolites increased rhizome production per plant Singh *et al.,* (2012) [57].

Pariari *et al.,* 2018 [60] reported that yield per plant (235.55 gm), yield per plot (11.30 kg) and yield per hectare (27.15 t/ha) were highest at GA3 at 150ppm sprayed plants and the number of fingers per clump (20.83), length of fingers (10.96) and girth of fingers (4.26) were found highest with plants sprayed with CCC at 500 ppm and could be recommended to the farmers of alluvial plains of West Bengal. Yield improvement characters may be due to the rapid proliferation of xylem parenchyma, formation of storage rhizomes earlier and production of more number of rhizomes also helpful in increasing the yield. Application of CCC @1000 ppm outperformed control and higher nutrient levels at N3 substantially under protected conditions with soil less culture medium and increased leaf number, area, and also dry matter production were preferred, which could have increased the yield. Chlorocholine Chloride (CCC) is a quaternary ammonium compound which inhibits the Copalyl Diphosphate Synthase (CDPS) and Kaurene Synthase (KS) in the GAs biosynthetic pathway leading to translocation of photoassimilates from the vegetative part to the underground rhizomes Arif *et al.*, 2022 [36].

The effect of Benzyl amino purine at 100ppm was explained by Bezabih *et al.*, 2017 [58] such that it is found to be effective in regulating the shoot growth for ginger grown under both pot and plain land and also in number of fingers/ rhizomes and also in rhizome width. There is decrease in the rhizome length and also in fresh weight in the higher concentration. Obasi *et al.*, 2004 [59] found that the rhizome yield was higher in CCC treated plants than that of the GA and ethrel. Jirali *et al.*, 2008 [68] reported that the fresh and dry rhizome yield, number of mother rhizomes and length and circumference of primary and secondary fingers were more by foliar application of CCC 500 ppm in ginger.

Role on quality aspects in ginger

The crude fiber content, essential oil content that can determine the quality of the ginger was found to be higher in plant sprayed with Cycocel a 500ppm and followed by Paclobutrazol at 250ppm Velayutham *et al.*, 2013 [56]. Cycocel by blocking the gibberellin synthesis can improve the oil content. Ravisankar 1983 [72], Jayachandran and Sethumadhavan 1988 [73] and Maruthi *et al.*, 2003 [55]. The essential oil content and the oleoresin contents were enchanced by 18.7% and 29.4% at 180 DAP and by 14.5% and 25.1% at 240 DAP by Tricoanthol application Singh *et al.*, 2012 [57]. There is a progressive increase in the rhizome and carbhohydrate content of the rhizome by increasing the TRIA levels, but at the higher doses there is a reduction in the values. The effect of TRIA in carbohydrate content may be due to the role in CO2 fixation and in the metabolism of sugars and starch (Ries 1991 [74]; Sharma *et al.*, 2002 [75]). Pariari *et al.*, 2018 [60] reported that the quality assigning characters attributing parameters like essential oil (1.74%), oleoresin content (5.15%) and dry recovery (20.87%) was recorded highest with CCC at 500 ppm respectively. The Cycocel application found to increase the chlorophyll content, increasing the photosynthetic rate and the strengthening of stems and also the oil and the oleoresin increased due to the application of CCC at 1000ppm was reported by Arif *et al.*, 2022 [36]. The efficient use of CCC in improving the quality and biochemical of ginger was due to the ability of CCC to block the gibberellin synthesis and due to efficient source and sink relationships Ullah and Bano., 2011 [76].

Effect on the yield, yield attributes and quality of turmeric

The yield parameters ie; yield per clump, yield per plot and yield per hectare was noticed to be high in NAA 20 ppm in turmeric Kumar *et al.* 2017 [65]. CCC at 1000 ppm (at 60 and 120 days after sowing) was very effective, in increasing both the fresh yield content of turmeric and also the dry rhizome yield by Jirali *et al.*, 2008 [66]. The fresh, dry and processed yield were higher in NAA 40ppm and is better than GA 50ppm and kinetin 40ppm Singh *et al.*, 2016 [67]. Dhanoji 2011 [78] had reported that the fresh yield of turmeric was found to be highest in Lihosin 0.05% spray followed by Alar 0.05% and FeSO4-0.5%+ZnSO4-0.05% spray as compared to control. He added that Lihosin can restructure the plant to produce optimum photosynthates and improving the source-sink relation there by improving the yield Gawande *et al.*, 2021 [22] found that length of mother rhizome, girth of mother rhizome, length of primary finger, girth of primary finger, weight of mother rhizome/plant, weight of primary finger/plant was found significantly superior in treatment combination primary finger as planting material and the growth regulators at CCC 500 ppm. Growth regulator, NAA 20ppm influenced the yield parameters significantly due to collective effect on cell elongation, cell division in turmeric var. Suroma Pujari *et al*., 2016 [68]. In summary, the outcome showed that seedlings grown in trays filled with a blend of 50% Coco peat and 50% Vermicompost, along with the application of a sea weed extract spray at a concentration of 0.2% at 15 and 30 days after transplanting, resulted in the highest fresh yield Datta *et al*., 2023 [79]. Yield and curcumin content was found to be higher in NAA@100mg/L treated Gujarati variety Navsari by Thounaojam *et al*., 2016 [69]. A significant effect was seen in curing percent, curcumin content, volatile oil content, lower crude fiber and ash content of turmeric, when mother rhizomes along with foliar spray of NAA @ 100 mg/l in turmeric Amarjeet *et al*., 2016 [80]. Maximum yield per plot and number of primary rhizomes, length of primary rhizomes found to be higher in GA 100ppm foliar spray Venugopal *et al*., 2017 [70]. Masroor *et al*., 2006 [71] reported that the foliar application of the 10^{-6} M Triacontanol + 1.0×10^{-5} M Kinetin (T3) ameliorate leaf-N content (R=0.999) and total chlorophyll content (R=0.997), curcumin yield in turmeric. Exogenous foliar application of Paclobutrazol on two different varieties of turmeric was noticed by Chungloo *et al.*, 2021 [81] and its effect on curcuminoids, photosynthetic abilities, total soluble sugar, and rhizome yield. The effect of the of homobrassinolide (HBL) sprayed in four different concentrations *viz*., 0.5µM, 1.0µM, 2.0µM, and 3.0µM was studied by Rajesh *et al.*, 2021 [82] and had found a positive effect in augmenting the saline stress and metabolite contents *viz*., chlorophyll pigments, carbohydrate fractions (reducing sugars, total sugar and starch), and soluble proteins in turmeric plants. Anusuya *et al.*, 2016 [83] studied the foliar application chitosan (growth promoter) in Turmeric var. Erode local, higher yield and curcumin content was reported.

Conclusion

Based on the available literature, it is clear that the application of plant growth regulators had a significant effect on its growth, physiology and yield of ginger and turmeric. There are several PGRs at several combinations and concentrations can be applied to the ginger and turmeric for better production and ginger. Further studies are needed to standardize cost effective plant growth regulators for better growth and yield of ginger and turmeric for enhancing the yield and marketability.

Conflict of interest

The author declares no conflicts of interest.

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