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Advances in Gibberellic Acid Application in Cropping

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

For plants to thrive, phytohormones play a key role in their development and growth. A total of five different phytohormones have been identified here: auxin, gibberellins, cytokinin, ethylene and abscisic acid. The growth-promoting and dormancy-breaking effects of gibberellin make it a crucial phytohormone. Japan was the site of its discovery around the end of the nineteenth century. The most often utilized type of gibberellic acid is GA3, which is a metabolite. Tobacco and lettuce, require bright light to germinate, and may be grown with the aid of gibberellic acid even in the dark. Internode elongation, like in the case of pea or maize suffering from dwarfism, is another benefit of GA. It aids in the development of seedless tomato and grape types. During germination, gibberellins in the aleurone layer of the endosperm of cereal grains release particular enzymes like amylase, which hydrolyzes starch to form simple sugars. These sugars are then transferred to the developing embryo to be used as a source of energy. Gibberellin plays a crucial role in fruit setting, and it also aids fruit development and increases fruit size, making it one of the most significant growth regulators.

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1. INTRODUCTION

As we know just like humans, plants too require hormones that are used in various aspects like for growth and development in them. The hormones in plants are also referred to as plant growth regulators (PGR). And these are defined as the substances that are chemically produced inside the plant and that affect the growth and separation of tissues, organs and cells in plants [57]. These naturally produced organic substance controls various physiological activities inside the plants [11]. Phytohormones maybe organic or synthetic. The PGR is commonly distributed into two categories: - growth retardants and growth promoters [28]. Naturally occurring phytohormones consist of ethylene, gibberellins, auxin, abscisic acid and cytokinin. The phytohormone that was first discovered was auxin in 1928 by Fritz W. Went [49]. Later on, other hormones such as gibberellin and cytokinin were discovered. All of these different hormones have different functions in the plants. The plant growth promoters are auxin, gibberellin and cytokinin while the retardants are ABA and ethylene.

Tetracyclic di-terpenoid chemical gibberellic acid (GA) is a plant hormone that promotes plant growth and development [35]. The phytohormone discussed in this paper is gibberellin or gibberellic acid which is a major growth promoter as well as it regulates the breakage of dormancy in seed along with its germination [23]. Gibberellic acid (GA3) has demonstrated notable progress in cropping practices, with a focus on improving crop quality, yield, and fruit set. It can also improve fruit size, lower seed weight, and increase the amount of fruit that is edible. Additionally, in an effort to maximize output and cut expenses, the manufacture of GA3 through fermentation techniques has been investigated, with a focus on the environmentally responsible sourcing of agro-industrial leftovers. When administered foliarly, GA3, a plant hormone, is essential for fostering plant growth and development. It influences processes like blooming, fruit set, and yield components in a variety of crops. The fungal disease in rice was seen in Japan during the late 19th century which led to the origin of research in gibberellins [36]. Other functions of GA are pollen maturation, stem elongation, flower induction and expansion of leaves [17]. It also plays various roles in physiological activities such as metabolism of starch, germination of seeds and elongation of cell [31] along with grain development [35]. It also plays a vital role in leaf senescence retardation [25]. In addition to its potential to rescue maize and pea dwarf mutants, gibberellic acid has been shown to trigger bolting and flowering in rosette species [36]. Numerous gibberellic acids, ranging from GA1 to GA126, have been discovered in vascular plants, fungi, and bacteria [47]. The synthesis action, crystallization as well as identification of GA was in the 1950s [14]. GA is one of the most essential phytohormones required for seed development, plant survival and production of crop success [35]. This review focuses on the role of gibberellic acid in plants and the different ways that plants use it.

2. HISTORY

GA was discovered in the late 19th century or early 20th century by Japanese scientist/researchers [11] [35]. There was a fungal disease in rice and the proof that a fungal infection was the cause of a rice illness characterized by, among other things, abnormally long seedlings and infertility [38] [36]. Japanese farmer Kurosawa noticed that some plants in rice fields were noticeably taller, thinner and whiter than ordinary plants, as well as having noticeably longer and narrower leaves than their unaffected neighbours [11]**.** Symptoms like this were traced back to the pathogenic fungus *Gibberella fujikuroi* by plant pathologists [35]. As early as 1912 [65] hypothesized that the disease was caused by a chemical' produced by a parasitic as comycetous fungus, *Gibberella fujikuroi* (the perfect form, appearing only seldom; the imperfect form is *Fusarium moniliforme*, infecting the afflicted plants [46]. He provided experimental evidence for this theory by showing that sterile filtrates of the fungus might cause signs of bakanae disease in otherwise healthy rice seedlings [11]. Diseases go under many different names that were employed by farmers in Japan; the most well-known of them is probably "bakanae," which means "silly seedling" or “foolish seedlings”. In-depth examination of the early studies that led to the identification, structural, and isolation elucidation of gibberellins, and the subsequent hypothesis that these molecules function as endogenous growth regulators in plants [54]**.** Japanese researchers in the 1930s grew this fungus in the lab and analyzed the culture filtrate to isolate an imperfect crystal of two fungal "compounds" that stimulated plant growth. Because it was originally discovered in the fungus *Gibberella*, one of these compounds is known as gibberellin A. Three distinct gibberellins, designated gibberellin A1, A2, and A3, were isolated and identified by researchers at Tokyo University in the 1950s. Based on the original naming of gibberellins A1 (as GA1), GA2, and GA3, the current numbering system for gibberellins has evolved over the past 50 years [35]. In the 1950s, western scientists learned about gibberellic acids for the first time and scientists in the United States and the United Kingdom recognized the significance of these chemicals and began conducting intensive research initiatives [36]**.** The substance extracted from the fungi was named as Gibberellic acid in United Kingdom while Gibberellin-X in the United States was same the as Gibberellin A3 in Japan. Commercial industrial-scale fermentations of Gibberella for agronomic, horticultural, and other scientific uses predominantly yield GA3 [35]. In addition to its capacity to rescue miniature maize and pea mutants, gibberellic acid was also discovered to trigger bolting and flowering in rosette species. Plant extracts can be achieve the same results, suggesting that gibberellins were already present in plants [36]. In 1958, gibberellin A1 (GA1) was isolated from immature seeds of the runner bean *Phaseolus coccineus*, proving this [48]. A system for sequentially numbering GAs (GA1 through GA4) was introduced in 1968 as more and more GAs were described, initially from *Gibberella* and later from other plant sources [35].

Table 1. Role of GA in plants and seeds (GA3)

Crops	Content	Action	References
Wheat	100ppm	Enhances the parameter for growth, photosynthetic pigments, and agricultural output. The inhibitory effect of salt stress on crop production of the two wheat cultivars was reduced by GA3 treatment, and the crop yield of the two wheat cultivars was raised.	[1]
Carrot	50ppm	Both of the carrot varieties were subjected to Pb stress, GA3 improved plant growth and chlorophyll content in the leaves. Furthermore, GA3 inhibited Pb uptake in carrot leaves and roots. Under Pb stress, GA3 also dramatically in the content of phenolic compounds in both carrot cultivars	[29]
Broad bean and lupin plant	100ppm	GA 3 application typically resulted in decreased chlorophyll and soluble carbohydrate concentrations in the absence and presence of Cd and Pb, but soluble protein contents were significantly enhanced.	[21]
Tomato	50ppm & 100ppm	Tomato plants with a 50ppm concentration had greater leaf area, weight, and height, flowered earlier by 50%, and set 5% more fruit. Fruit size may be noticeably boosted at 100 ppm. Fruit setting, fruit drop before harvest, and fruit production are all influenced by gibberelic acid. Tomato seed germination, timing, leaf count, leaf area, branch count,	[57]

Crops	Content	Action	References
		plant height, flower count, fruit cluster count, fruit cluster count, fresh fruit weight, fruit yield, ascorbic acid total soluble solids, and dry matter are all positively affected.	
Potato	0, 5 and 10 mg/lit	It was discovered that applying gibberellic acid at lower concentrations (5 and 10 mg/lit) improved the general performance and productivity of potato seed tubers. When applied to seed tubers, gibberellic acid boosted yield across the board. When compared to the control group, the total weight of seed tubers grown in soil treated with 5 mg/lit GA3 was significantly different (p 0.05). In addition, following a week of GA3 spraying, the starch content of potato tubers dropped while the sugar content rose. When treated with GA3, tubers began sprouting far sooner than controls. As we have mentioned, sugar content is a major factor in deciding whether or not seed potatoes will sprout.	[5]
Black mulberry	1000 and 2000 mg l^{-1}	The highest germination rate (between 60% and 70%) was achieved with this method. The germination rate for seeds that were stratified for 100 days was 88%. 96% of seeds germinated post-exposure to 250 mg l^{-1} GA3 and then stratified for 100 days. Increasing the GA3 concentration resulted in taller plants and longer growing seasons.	[28]
Linseed	0, 10-8 and 10-6 M	Increases dry weight per plant by 40.5% and PN by 12.2% at 75 DAS, also boosts seed output by 24.7%, oil yield by 27.1%, and fibre yield by 55.9 % per plant at the time of harvest.	[63]
Citrus	400ppm	The maximum percentage of plant height, seed germination, number of leaves, stem diameter, root length, number of roots and fresh weight of the resulting seedling were all improved.	[58]
Chickpea	0,10-7 ,10-6 and 10-5M	The parameters such as the leaf area per plant, shoot length, carbonic anhydrase, pod number, seed yield per plant and protein content were enhanced with 8 hours of soaking treatment with 10-6MGA.	[50]

Crops	Content	Action	References
		Furthermore, at the 90 DAS stage, the aforementioned metrics were improved by 69.33%, 68.72%, and 87.06%, respectively, in comparison to the control. Protein content, pod production, and seed output all increased by 82.69, 5.44 and 54.32%	
Carnation	20ppm	Results showed that the germination rate for *Dianthus caryophyllus* was increased by Gibberellic acid (GA3) compared to that of Kinetin and Indole 3-acetic acid (IAA)	[64]
Submerged deep-water rice	0.01 to 0.2 micromolar GA3s	When 1 microliter per liter of ethylene was introduced to the air in the chamber where the sections were incubated, internodal elongation increased by a factor of two to eight. Internode cell division and elongation in rice were both stimulated by GA3 and ethylene. Internodal elongation may be induced by ethylene in rice through an increase in the production of endogenous GAs.	[62]
Garden pea	gibberellin (GA)-biosynthesis mutations, lh^{i}, *ls* and le^{5839}	These findings point to an early role for GAs (perhaps GA1 and/or GA3) in pea seed development, possibly in the regulation of embryo and/or endosperm formation.	[70]
Sunflower		Reducing sugar concentration was raised by gibberellic acid, notably in K-deficient plants.	[18]
Sweet sorghum		The dry weight, fresh weight, root length, and stem length were all altered by GA3 and PBZ treatments. GA3 application resulted in increased stem and root lengths as well as increased fresh and dried stem weights.	[27]
Jojoba seed	0, 50, 100 and 150ppm	Seed yield per feedan (2200, 2145 kg) and seed lipid content (57.6 and 58.55%) were both highest for the 75ppm ZnSO4 plus 150ppm GA3 treatment, which also produced the longest main branches (99.36 and 103.46 cm) and secondary branches (55.82 and 58.36 cm). It has been suggested that treating jojoba with 75ppm ZnSO4 and 150ppm GA3 will enhance its desirable characteristics, increasing its market value as a promising tree with prospective utility in the biofuel, chemical, and pharmaceutical	[4]

Crops	Content	Action	References
		industries.	
Black Cumin	5, 10 or 15 h in 10–6, 10–5, or 10–4M aqueous solution of GA.	Stomatal conductance (gs), leaf chlorophyll (Chl) content, carbonic anhydrase (CA) activity, total protein content, nitrate reductase (NR) activity, net photosynthetic rate (PN), capsule number, and seed yield at harvest were all measured in the potted plants at 50, 70, and 90 days after planting (130 days after sowing). Overall, the hormone treatment significantly improved all of these measures. Most notably, when 10-5M GA was applied for 10 hours before sowing, the values for PN, CA and NR activity, and seed yield were increased by 44, 40, 30, and 40%, respectively, compared to the control at the 70-day stage.	[67]
Safflower		While GA3 did enhance total stem weight, it harmed leaf weight, flower bud count, and seed output in field experiments. As a result, GA3 favoured vegetative expansion over sexual differentiation.	[55,56]
Mustard	0, 25 and 50 ~tM GA3	Translocation of dry matter to the developing sink is supported by the increased 1000 seed mass and pod number in GA 3 treated plants. This led to an increase in the quantity of seeds available.	[42]
Cowpea	0, 60, and 120 ppm	To increase cowpea plant tolerance to drought stress, gibberellic acid and glycine betaine were used to enhance important plant components and limit ion loss via ion leakage by modulating cell permeability.	[51]
Okra	0.1 mM GA_3	When applied to the leaves of okra seedlings, GA3 and/or AsA helped them thrive in saline conditions. Seedlings of okra by enhancing growth parameters, raising chlorophyll and carotenoid levels, boosting antioxidant enzyme activity, and lowering electrolyte leakage, H2O2 levels, and lipid peroxidation.	[72]
Canola	100ppm	Both seed production and seed oil content were increased by 13.3-17.7% and 28.9-29.8% respectively, when gibberellic acid and salicylic acid were applied together to canola plants throughout the growing season. Canola grown in arid settings will benefit from the addition	[39]

Crops	Content	Action	References
		of salicylic acid and gibberellic acid in combination with nitrogen (at 100/120 kg ha-1) as a means to address growing concerns over food security.	
Rice seeds	0, 10, 30 and 60 mg/L	Increased germination and a-amylase activity in response to increased GA3 concentration and seed soaking time	[12]
Bell pepper	10000 mg 1^{-1}	GA3 functioned as an androecide when sprayed on bell pepper, *Capsicum annuum L*., 10 days before and after the plant began flowering.	[7]
Mungbean	GA3 applied in 3 concentrations B1: 0ppm, B2: 50ppm, B3: 100ppm	The height of plants was significantly affected by the addition of gibberellin (50ppm) Maximum dry forage yield was achieved with 50 ppm gibberellin. Increased flowering due to 100 ppm GA3	[20]
Coriander	50 ppm	Results showed that coriander seed growth and yield were both increased after the treatment of gibberellic acid. The best method for using gibberellic acid to increase coriander growth and yield was to soak the seeds in water before sowing them, spray them at the leaf stage, and then spray them again when they were 50 percent in bloom.	[45]
Marigold	150 ppm	The no-pinching treatment with GA3 application at 150 ppm resulted in the highest dry weight of leaf, fresh weight of leaf, day to-bud initiation, blooming duration, bud length, and the number of petals per flower.	[69]
Onion	0, 50, 100 and 150 ppm	Significant on parameters like plant height, leaf count per plant, highest flower stalk count, umbel count per plant, bud count per umbel, percent flowering at 45 and 60 days after planting, seed count per umbel, seed weight per umbel, seed count per plant, seed count per plot, 1000 seed weight, seed yield, fruit count per umbel, fruit set percentage per umbel, and germination rate per plant. When vernalization was performed at 5°C for 14 days while also applying 100 ppm GA3, the resulting seed production was deemed optimal (280.42 kgha-1).	[43]
Ber	200ppm	Maximum germination rates of 98.76% and 77-82%	[37]

Crops	Content	Action	References
Jackfruit	100ppm	The highest germination rate (95.33%), the highest coefficient of germination velocity (27.67%), the tallest plants (26.78 cm), the shortest germination time (13 days), and the fastest germination time (13 days) all belonged to these seeds (3.61 days).	[68]
Guava	3000ppm	Boost the percentage of seeds that germinate (83.2%), plant height, leaf count, and leaf size.	[59]
Aonla	500ppm	The earliest germination, highest germination rate, lowest mortality rate, largest seedlings in terms of height (72.94 cm) and girth (0.63 cm), highest percentage of buddable seedlings (80.44%), and highest germination rate overall (75.50%) were all achieved (8.0 days)	[61]
Wood apple	100-150ppm	Germination was 25%	[73]
Custard apple	500ppm	Germination was improved	[73]
Mango	100,200ppm	Growth, fruit retention, yield and quality were the highest	[60]
Pear	2.7%	Increase fruit production. Fruit size at maturity is enhanced.	[16]
Blueberry	0.4mM	Fruits are getting more and having less fruit.	[15]

3. GA IN SEED GERMINATION AND BREAKING OF SEED DORMANCY

The term "germination" refers to the sequence of events that begins with the dormant dry seed absorbing water and ends with the embryonic axis growing longer [9]. It is common practice to refer to the moment when the radicle has penetrated the structures surrounding the embryo as "visible germination," indicating that the process of germination is complete [10]. Dormancy is the state in which the seed cannot germinate into a new plant and this may be due to various factors. Any germination unit that does not sprout within a certain amount of time while exposed to typical physical environmental variables (temperature, light/dark, etc.) that are otherwise favourable for its germination is considered to be dormant [6]. Some physical elements (light, temperature and moisture) and the endogenous growth-regulating hormones influence the breaking of seed dormancy to germination (Gibberellic Acid and Abscises Acid) [35]. The GA helps break the dormancy of the seed while ABA promotes it [19]. A variety of plant growth and development processes are stimulated by gibberellic acid (GA), with germination, increased length and earlier flowering being the most well-known. Important participants in this pathway include the DELLA repressors.GA influences development in two ways: by elevating embryonic growth potential and by stimulating the production of hydrolytic enzymes [53] [44] [26]. According to research conducted on Arabidopsis, the release of embryonic GA during seed germination weakens the seed coat by increasing the expression of genes involved in cell growth and differentiation [24]**.** To increase the production of the hydrolytic enzyme α-amylase in the aleuron layer of sprouting cereal grains, GAs act as a natural regulator of the processes involved in seed germination [74] [66]. There are three distinct components of a cereal grain: the embryo, the endosperm, and the seed coat. Aleuron and starchy endosperm are both parts of the endosperm. The mature, non-living starchy endosperm is made up of thin-walled cells containing starch grains and encircled by the aleuron layer, whose cells have thick walls and protein bodies. As a result, the starchy endosperm's food reserves are broken down into soluble sugars, amino acids, and other compounds that are delivered to the developing embryo [35]. Expression of the genes encoding the GA biosynthetic enzymes GA 20-oxidase and GA 3-oxidase is restricted to the epithelium and the short developing tissues of the germinating embryo in rice [41]. Both biosynthesis and reaction to GA appear to occur in the embryo, but only response in the aleurone layer. Both locations provide a different answer. The aleurone is where -amylose is synthesized, whereas in the growing shoot cells divide and elongate. Exogenous GA increases α-amylase gene expression via the SLN1 and GAMYB transcription [33]. In contrast, gene expression in barley is repressed by PKABA1, an ABA-responsive serine/threonine protein kinase [30]. In addition to inducing the release of hydrolytic enzymes, GA combines with reactive oxygen species to set off the programmed cell death pathway. Many new genes whose regulation is up- or down-regulated by GA and ABA treatment in barley have been discovered thanks to the aleuron gene expression pattern [35]. Dwarf phenotypes are caused by mutations in genes responsible for GA signalling in rice aleurone cells [71]. In tomato and tobacco, the endosperm caps are a significant physical barrier to germination that must be broken for radical emergence to occur [35]. The GA-deficient-1 (gib-1) mutant of tomato and *Arabidopsis* ga1–3 mutant could not germinate without exogenous GA application; however, it germinated when endosperm caps were removed [32]. The weakening of the endosperm cap is mostly due to GA's involvement. Characterization at the physiological and biochemical levels demonstrated that bioactive GAs is synthesized in the embryo, transferred to the aleurone layer [22] and induce the production of α-amylase [34]**.** The aleurone layer, which is unable to generate GA but can detect GA signals, is thought to be involved in seed germination [35].

4. RELATION OF GA WITH OTHER PHYTOHORMONES

4.1 Auxin

Green pea-stem sections could only lengthen in response to light when treated with gibberellic acid (GA) and an auxin. Three-indolylacetic acid, 2-methyl-4-chloro-phenoxyacetic acid, two-and-a-half-dichloro-phenoxyacetic acid, and I-naphthylacetic acid were the most potent auxins at increasing section extension and eliciting a response to GA. Internodes cut from plants that had been pretreated with GA grew noticeably quicker in vitro compared to those cut from untreated plants only when an auxin was also present in the incubation medium [13].

Increased internode elongation in response to GA and GA plus IAA was seen in stoloniferous plants like strawberries with a well-balanced auxin-gibberellin system. Applications of GA or TIBA stimulated expansion in erect plants, which appear to have suboptimal auxin levels. The tropistic response of stoloniferous plants to GA and GA plus IAA provides further support [8].

4.2 Cytokinin

In general, GA3 and CK greatly enhanced the suppressed plant characteristics, but the exact magnitude of this effect varied by growth stage and hormone type/concentration. We observed that GA3 and CK were equally effective in lowering the negative effects of drought on maize throughout its vegetative phase. The degree to which the hormone concentrations had a calming effect was variable. When applied at 150 mg Ll, CK showed excellent results, leading to a 106% yield advantage over drought stress and a 79.9% increase over well-watered controls. On the other hand, GA3 at 50 mg Ll performed admirably, increasing grain production by 78.8 [2].

In sorghum, adding cytokinin (CK) or gibberellic acid (GA), or a combination of the two, to soil with high salinity might stimulate growth in a manner analogous to that produced by the elevated concentration of mineral nutrients. These results suggest that an imbalance in phytohormones, rather than a mineral deficit, inhibits development at 300 mol m3 NaCl in the presence of half-strength Hoagland solution, suggesting that the effects of phytohormones and increasing mineral concentration are identical. The shift in mineral concentration in the nutrient medium appears to operate as a signal implicated in hormonal balance that permits growth at high salinity, in addition to its nutritive effect. When Sorghum is subjected to 300 mol m3 NaCl, the range of nutrient concentrations that can sustain growth is reduced. Changing the nutrient content may trigger the production of growth-promoting CK and GA on the inside of the plant. Growth is suppressed and adaptation is blocked by the administration of CK or GA at analogous quantities during the adaptation (pretreatment) period. Timing of exogenous phytohormone therapy is critical for maximizing responsiveness to salinity stress [3].

4.3 Abscisic Acid

In this study, we looked at how the plant hormones gibberellic (GA) and abscisic acid (ABA) affected the respiration rate of persimmon fruit as it grew and ripened. Five applications of GA (100 ppm) were made to fruiting branches as a whole during development stage II, while a single application of ABA (100 or 250 ppm) was made to each fruit before entering growth stage III. Phase III fruit development was slowed by GA treatment, which slowed the fruit's coloration and softening. The opposite was true with ABA, which led to improved fruit colour and a modest boost in fruit growth. As a result of these changes, the respiration rate of the fruit was decreased by GA treatment and increased by ABA therapy. In addition, the increase in respiration that accompanied the start of development stage III was slowed in GA-treated fruit whereas speeded up in ABA-treated fruit. Based on these findings, it appears that the final swelling and maturity of persimmon fruit are closely related to the high respiration rate observed during growth stage III. The increase in respiration seen at the start of growth stage III may be an important component in driving the transition from the second to the third phase of development [52].

4.4 Ethylene

Abscisic acid blocked gibberellic acid's ability to stimulate α-amylase synthesis in barley (*Hordeum vulgare L.*) aleurone layers, whereas extra gibberellic acid and ethylene alleviated the blockade to a lesser extent. Abscisic acid inhibits amylase synthesis, although adding more gibberellic acid and ethylene nearly nullifies this effect [40].

5. CONCLUSION

GA is one of the major phytohormone that performs various function including seed germination, breaking dormancy, stem elongation, elongation of internodes, bolting, flowering and also parthenocarpy. It also plays an important role in germination, tolerating drought stress, salinity and other physical stress in various cereal crops, pulses, fruit crops, oilseeds as well as ornamental crops. It mostly has positive response to any plants or seeds. It is an essential phytohormone for the survival of plants. Many GA3 commercial products are available and well-documented, making their usage in a wide variety of cultivars possible. Especially in India, one of the world's most important agriculture-based economies, the search for novel and inexpensive GA3 production techniques would surely increase its applicability, benefitting the quality and productivity of numerous cultivars across the globe.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

I, Vastavik Sharma, hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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