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Enhancing Fruiting, Yield, and Quality of Litchi with the Use of Gibberellic Acid and Zinc Sulphate

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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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Abstract

An experiment was conducted during 2025 at the Horticulture Garden, Department of Fruit Science, College of Horticulture, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, to evaluate the effects of gibberellic acid (GA_3) and zinc sulphate ($ZnSO_4$), applied alone or in combination, on fruiting, yield and quality of 66-year-old litchi (*Litchi chinensis* Sonn.) cv. Rose Scented trees. Nine treatments were evaluated in a randomised block design with three replications, using one tree per treatment unit. A single foliar spray was applied after fruit set, and observations were recorded at 15-day intervals until harvest. The combined treatment GA_3 at 50 ppm + $ZnSO_4$ at 1.0% (T_9) produced the highest fruit counts at the pit-hardening (30.15) and ripening (24.59) stages, fruit length (4.56 cm), fruit diameter (4.59 cm), fruit weight (19.49 g), pulp weight (13.99 g), pulp: stone ratio (4.70), total sugar (14.83%), total soluble solids (22.97 °Brix), sugar: acid ratio (36.66) and fruit yield (53.06 kg/tree). It also recorded the lowest fruit cracking (1.68%), seed weight (2.98 g), rind weight (2.46 g) and titratable acidity (0.404%). T_8 (GA_3 at 50 ppm + $ZnSO_4$ at 0.5%) generally ranked next. These results indicate that a single post-fruit-set foliar application of GA_3 at 50 ppm with $ZnSO_4$ at 1.0% may improve fruit retention, quality and yield of cv. Rose Scented under the sub-tropical plains of Central Uttar Pradesh.

Keywords: Litchi; gibberellic acid; zinc sulphate; fruit cracking; yield and quality.

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1. Introduction

Litchi (*Litchi chinensis* Sonn.), a member of the family Sapindaceae, is one of the most prized sub-tropical fruits, valued for its translucent, juicy aril, delicate flavour and attractive appearance. The fruit is a rich source of vitamin C, polyphenols and readily digestible sugars, and commands a premium in both domestic and export markets during its short early-summer season. Despite its commercial importance, litchi cultivation is beset by two persistent physiological constraints: excessive pre-harvest fruit drop and fruit cracking, which together can account for substantial yield losses between fruit set and harvest (Marboh *et al*., 2017). Both disorders are closely linked to the hormonal and nutritional status of the developing fruit, an association that has directed research attention towards the foliar use of plant growth regulators and micronutrients as a practical means of improving fruit retention and quality.

According to the First Advance Estimates (2025–26) released by the Department of Agriculture & Farmers Welfare, Government of India, litchi is cultivated over 74.55 thousand hectares with an estimated production of 733.08 thousand metric tonnes in the country. Bihar continues to be the leading litchi-producing state, contributing the largest share of national production, followed by West Bengal, Jharkhand, Uttarakhand, Assam, Punjab, Odisha and Chhattisgarh. The favourable agro-climatic conditions of the Indo-Gangetic plains make northern and eastern India the major litchi-growing regions (Department of Agriculture & Farmers Welfare, 2026).

Gibberellic acid (GA_3) is widely used to regulate fruit growth and reduce abscission in a range of fruit crops. It is believed to act by suppressing hydrolytic enzymes, such as cellulase and polygalacturonase, that operate in the pedicel abscission zone, and by raising endogenous auxin levels that antagonize ethylene-mediated fruit drop. In litchi, foliar GA_3 has been reported to increase fruit weight and size and to delay senescence of the pericarp (Chang & Lin, 2006; Nand *et al*., 2023b). Zinc, commonly applied as zinc sulphate ($ZnSO_4$), is an essential micronutrient that functions as a precursor of tryptophan—the biosynthetic substrate for indole-3-acetic acid—and as a cofactor for numerous enzymes governing carbohydrate and protein metabolism. Adequate zinc nutrition has been associated with improved fruit set, reduced cracking and better pericarp strength in litchi and other fruit crops (Jana *et al.,* 2010).

Recent field studies in litchi indicate that foliar zinc and other bioregulator treatments can influence fruiting, marketable yield and fruit quality attributes, although the magnitude of response depends on the cultivar and treatment combination (Rawat & Tripathi, 2024; Nayak *et al*., 2024).

Current literature also treats fruit cracking as a multifactorial disorder involving fruit-skin structure and hormone-related processes, while zinc-containing treatments have been associated with fruit set and quality responses in another perennial fruit crop (Santos *et al*., 2023; Darwesh *et al*., 2023).

The study was designed to address the unresolved practical question of how a single post-fruit-set foliar application of GA_3 at 25–50 ppm, alone or with $ZnSO_4$ at 0.5–1.0%, affects fruit retention, cracking, quality and yield in mature litchi cv. Rose Scented in the sub-tropical plains of Central Uttar Pradesh. This cultivar-specific treatment context constitutes the research gap examined in the present experiment.

Accordingly, the objective of the present study was to evaluate the effects of GA_3 and $ZnSO_4$, applied alone and in combination after fruit set, on fruit retention, fruit cracking, physical and biochemical quality attributes, and yield of 66-year-old litchi cv. Rose Scented trees in the sub-tropical plains of Central Uttar Pradesh.

2. Materials and Methods

The present investigation was carried out during 2025 in the Horticulture Garden, Department of Fruit Science, College of Horticulture, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur (U.P.), situated between 25.26° and 26.28° N latitude and 79.31° and 80.34° E longitude at an elevation of about 126 m above mean sea level, in the alluvial belt of the Gangetic plains of Central Uttar Pradesh. The area experiences a sub-tropical, semi-arid climate with hot, dry summers (35-48 °C, April-June) and cold winters (as low as 8 °C), and receives 800–850 mm of annual rainfall, most of which is concentrated in the monsoon months of June to September. Standard weekly meteorological data (temperature, relative humidity, wind speed, evaporation, rainfall and sunshine hours) were recorded by the Department of Agronomy of the University throughout the cropping period (March–May 2025).

Twenty-seven uniform, healthy, sixty-six-year-old trees of litchi cv. Rose Scented, spaced at 10 × 10 m and maintained under a common, clean cultivation regime, were selected for the study. Three representative branches of similar vigour were tagged on each tree for recording observations. The composite soil sample (0-15 cm depth) taken before treatment application was analysed at the University Soil Testing Laboratory; the soil was sandy loam in texture, slightly acidic to neutral in reaction, and low in organic carbon and available nitrogen, but medium in available phosphorus and potassium.

The trees received a basal dose of well-rotten farmyard manure (25 kg/tree) in early January, along with urea (1.6 kg), single superphosphate (2.25 kg), and muriate of potash (0.60 kg) at recommended rates. Standard irrigation (at 15-day intervals after fruit set) and plant protection measures were applied uniformly across all treatments. The experiment was laid out in a Randomised Block Design (RBD) with nine treatments and three replications, with one tree per treatment as the unit of replication.

Stock solutions of GA_3 (25 and 50 ppm) were prepared by first dissolving the requisite quantity in a small volume of alcohol before making each solution up to the final volume with distilled water; $ZnSO_4$ solutions of 0.5% and 1.0% were prepared by dissolving 50 g and 100 g of salt, respectively, in 10 litres of water. A single foliar spray of the respective treatment solution was applied to each tagged tree soon after fruit set (18 March 2025), using a pneumatic foot sprayer fitted with a fine nozzle, at a rate of about 10 litres per tree, which was sufficient to thoroughly drench the foliage. Observations on fruiting and quality parameters were recorded at fifteen-day intervals from spraying until harvest (19 May 2025).

Fruit count at the pit-hardening and ripening stages was recorded on the tagged branches; fruit cracking was recorded as the percentage of cracked fruits on the tagged branches. Fruit length and diameter were measured with a vernier calliper on ten mature fruits per replication, and fruit pulp, seed and rind weights were recorded on an electronic balance, from which the pulp: stone ratio was derived. Total soluble solids were measured with a hand refractometer and corrected for temperature; titratable acidity and total sugars were estimated using standard volumetric methods described by the Association of Official Analytical Chemists (Latimer, 2019). Yield of marketable, sound fruit was recorded on a per-tree basis and expressed in kg/tree. All data were statistically analysed using the Randomised Block Design as described by Panse and Sukhatme (1985); treatment means were compared using the standard error of the mean (SEm±) and the critical difference (CD) at the 5% level of probability.

3. Results and Discussion

3.1 Fruit Retention, Cracking and Fruit Length

The data on fruit retention, fruit cracking and fruit length are presented in Table 1. fruit count at the pit-hardening stage ranged from 25.67 (T_1, control) to 30.15 (T_9), while fruit count at the ripening stage ranged from 19.14 (T_1) to 24.59 (T_9). At both stages, T_9 (GA_3 @ 50 ppm + $ZnSO_4$ @ 1.0%) recorded the maximum retention, closely followed by T_8 (GA_3 @ 50 ppm + $ZnSO_4$ @ 0.5%) and T_7 (GA_3 @ 25 ppm + $ZnSO_4$ @ 1.0%), with a consistent, near-linear improvement as the concentration of either input was raised, with combined treatments consistently outperforming the corresponding sole applications. The improved retention under combined GA_3 and zinc application may be attributed to the suppression of hydrolytic enzyme activity (cellulase, polygalacturonase) in the pedicel abscission zone by GA_3, together with the role of zinc as a precursor of tryptophan for auxin biosynthesis; together, these mechanisms may delay abscission and sustain fruit development through to maturity. Comparable synergism between GA_3 and zinc in improving fruit set and retention has been reported by Bhadauria *et al.* (2018) in aonla and Nand *et al.* (2023a) in litchi.

Fruit cracking declined progressively with increasing concentrations of GA_3 and $ZnSO_4$, from 4.24% under the control (T_1) to a minimum of 1.68% under T_9, with T_8 (2.61%) and T_7 (2.77%) showing the next-lowest values. Fruit length showed the converse trend, rising from 3.07 cm (T_1) to a maximum of 4.56 cm (T_9). The reduction in cracking under the combined treatment is consistent with GA3's role in promoting the synthesis of cellulose, hemicellulose, and pectin in the pericarp, thereby improving its elasticity and tensile strength. At the same time, zinc contributes to pericarp rigidity through its roles in protein and lignin synthesis, and it protects membranes from oxidative stress as a cofactor of superoxide dismutase. The concurrent increase in fruit length reflects the stimulatory effect of GA_3 on cell division and cell elongation, aided by zinc-dependent protein and nucleic-acid synthesis in the meristematic fruit tissue. These findings are consistent with earlier reports of reduced litchi fruit cracking and improved fruit size under combined micronutrient and growth-regulator sprays reported by Marboh *et al.* (2017), Jana *et al.* (2010), and Panwar *et al.* (2018) in litchi.

3.2 Fruit Diameter, Seed Length, Seed Diameter and Fruit Weight

The data on fruit diameter, seed length, seed diameter and fruit weight are presented in Table 1. Fruit diameter increased steadily with treatment, from 2.61 cm under the control to 4.59 cm under T_9, following a trend parallel to fruit length and confirming the effectiveness of combined GA_3 and zinc sprays in promoting overall fruit growth. Seed length and seed diameter, in contrast, both decreased with increasing treatment concentration, from 2.57 cm to 2.00 cm and from 1.93 cm to 1.19 cm, respectively, between the control and T_9, indicating a shift in the balance of assimilate partitioning away from the seed and towards the pulp under hormone and micronutrient treatment. Fruit weight correspondingly increased from 16.98 g (control) to a maximum of 19.49 g under T_9, followed by T_8 (19.43 g) and T_7 (18.53 g). The shrinkage of the seed alongside the marked gain in fruit weight reflects preferential translocation of photosynthates towards pulp development under GA_3 and zinc nutrition, a pattern reported previously in litchi and related crops receiving combined foliar treatments. The present findings are in agreement with the reports of Nand *et al*. (2023a) and Rani and Brahmachari (2001) in litchi, and Singh *et al.* (2017) in mango.

3.3 Pulp Weight, Seed Weight, Pulp: Stone Ratio and Rind Weight

The data on pulp weight, seed weight, pulp-to-stone ratio, and rind weight are presented in Table 2. Pulp weight, the principal determinant of the edible portion of the fruit, increased from 10.47 g under the control to 13.99 g under T_9, with T_8 (13.83 g) close behind, while seed weight fell correspondingly from 3.73 g (control) to 2.98 g (T_9). This inverse relationship between pulp and seed weight is consistent with the hypothesis that GA_3 and zinc jointly redirect assimilates from seed development to pulp accumulation, thereby improving the marketable edible fraction of the fruit. The present findings are in conformity with the reports of Bhadauria *et al.* (2018) in aonla and Nand *et al.* (2023a) and Dutta *et al.* (2011) in litchi.

The pulp: stone ratio, a key index of the edible-to-inedible fraction, increased from 2.81 under the control to a maximum of 4.70 under T_9, followed by T_8 (4.38), while rind weight declined from 2.79 g (control) to 2.46 g under T_9. The combined increase in pulp: stone ratio and reduction in both seed and rind weight together confirm that GA_3 and zinc favourably alter fruit composition in favour of the consumable pulp, in agreement with earlier observations on litchi quality improvement under bio-regulator and micronutrient sprays reported by Nand *et al.* (2023a) and Rani and Brahmachari (2001) in litchi, and Tripathi and Shukla (2006) in strawberry.

Table 1. Effect of GA_3 and $ZnSO_4$ on fruit count at pit-hardening and ripening, fruit cracking, fruit length, fruit diameter, seed length, seed diameter and fruit weight

Treatments with notations	Fruit count at pit-hardening	Fruit count at ripening	Fruit cracking (%)	Fruit length (cm)	Fruit diameter (cm)	Seed length (cm)	Seed diameter (cm)	Fruit weight (g)
T_1-Control	25.67	19.14	4.24	3.07	2.61	2.57	1.93	16.98
T_2-GA_3 @ 25ppm	27.93	21.20	3.35	3.49	3.88	2.43	1.60	18.32
T_3-GA_3 @ 50ppm	28.11	21.47	3.13	3.83	3.99	2.37	1.59	18.38
T_4-$ZnSO_4$ @ 0.5%	26.18	20.08	3.89	3.23	3.49	2.51	1.66	17.94
T_5-$ZnSO_4$ @ 1.0%	27.38	20.63	3.41	3.37	3.51	2.44	1.61	18.18
T_6-GA_3 @ 25ppm + $ZnSO_4$ @ 0.5%	29.34	21.67	2.93	3.98	4.04	2.33	1.47	18.50
T_7-GA_3 @ 25ppm + $ZnSO_4$ @ 1.0%	29.37	21.89	2.77	4.17	4.10	2.17	1.42	18.53
T_8-GA_3 @ 50ppm + $ZnSO_4$ @ 0.5%	29.46	23.26	2.61	4.18	4.23	2.06	1.34	19.43
T_9-GA_3 @ 50ppm + $ZnSO_4$ @ 1.0%	30.15	24.59	1.68	4.56	4.59	2.00	1.19	19.49
SE (m) ±	0.38	0.97	0.45	0.24	0.19	0.24	0.10	0.38
C.D. at 5% level	1.13	2.91	1.35	0.71	0.58	0.34	0.30	1.14

Table 2. Effect of GA_3 and $ZnSO_4$ on pulp weight, seed weight, pulp: stone ratio, rind weight, titratable acidity, total sugar, TSS and sugar: acid ratio

Treatments with notations	Pulp weight (g)	Seed weight (g)	Pulp: stone ratio	Rind weight (g)	Titratable acidity (%)	Total sugar (%)	TSS (°Brix)	Sugar: acid ratio
T_1-Control	10.47	3.73	2.81	2.79	0.634	12.37	19.17	19.51
T_2-GA_3 @ 25ppm	12.29	3.41	3.67	2.62	0.543	13.49	20.84	24.49
T_3-GA_3 @ 50ppm	12.53	3.38	3.76	2.58	0.531	13.60	21.02	25.37
T_4-$ZnSO_4$ @ 0.5%	11.81	3.47	3.41	2.66	0.568	12.86	20.65	23.10
T_5-$ZnSO_4$ @ 1.0%	12.46	3.43	3.55	2.62	0.549	13.10	20.75	24.05
T_6-GA_3 @ 25ppm + $ZnSO_4$ @ 0.5%	12.57	3.29	3.77	2.56	0.526	13.79	21.18	26.47
T_7-GA_3 @ 25ppm + $ZnSO_4$ @ 1.0%	12.71	3.26	3.81	2.53	0.511	14.03	21.66	27.20
T_8-GA_3 @ 50ppm + $ZnSO_4$ @ 0.5%	13.83	3.16	4.38	2.50	0.446	14.54	22.37	32.67
T_9-GA_3 @ 50ppm + $ZnSO_4$ @ 1.0%	13.99	2.98	4.70	2.46	0.404	14.83	22.97	36.66
SE (m) ±	0.54	0.12	0.32	0.05	0.04	0.41	0.58	3.18
C.D. at 5% level	1.63	0.35	0.97	0.15	0.12	1.22	1.73	9.54

3.4 Titratable Acidity, Total Sugar, TSS and Sugar: Acid Ratio

The data for titratable acidity, total sugar, total soluble solids (TSS), and sugar: acid ratio are presented in Table 2. Titratable acidity declined progressively with treatment, from 0.634% under the control to a minimum of 0.404% under T_9, while total sugar content increased correspondingly, from 12.37% (control) to 14.83% under T_9. The concurrent fall in acidity and rise in sugars is generally attributed to enhanced translocation of carbohydrates into the fruit and to the metabolic conversion of organic acids to sugars during ripening, a process that GA_3 and zinc appear to accelerate by improving overall fruit metabolic activity. Similar biochemical shifts under GA_3 and micronutrient sprays have been documented in litchi. The observed biochemical improvements are in conformity with the findings of Panwar *et al.* (2018) in litchi, Singh *et al.* (2017) in mango, Kumar *et al.* (2022) in mango, Rathore *et al.* (2009) in litchi, Gupta *et al.* (2022) in litchi, and Tripathi and Kumar (2022) in mango.

Total soluble solids (TSS) increased from 19.17 °Brix under the control to a maximum of 22.97 °Brix under T_9, and the sugar: acid ratio – widely regarded as the best single index of fruit palatability – rose from 19.51 (control) to 36.66 under T_9, nearly double the control value. Both trends parallel the changes already noted in sugar and acid content and indicate that fruits from T_9-treated trees would be perceptibly sweeter and more palatable than those from untreated trees, consistent with earlier reports of improved TSS and sugar: acid ratio in litchi following GA_3 and zinc application. The present findings are in agreement with the reports of Kumar *et al*. (2022) in mango, Rathore *et al.* (2009) in litchi, Gupta *et al.* (2022) in litchi, and Pandey *et al.* (2011) in ber.

3.5 Fruit Yield

Fruit yield (Fig. 1), the principal economic parameter of the study, increased markedly and consistently with treatment, from 40.57 kg/tree under the control to a maximum of 53.06 kg/tree under T_9, followed by T_8 (50.11 kg/tree) and T_7 (48.49 kg/tree). The substantial yield gain under combined GA_3 and zinc application is the cumulative outcome of the improvements already noted in fruit retention, fruit size and fruit weight, and confirms that balanced foliar nutrition with a growth regulator and a micronutrient is an effective strategy for raising litchi productivity, in line with earlier reports of yield enhancement in litchi through combined bio-regulator and micronutrient sprays. The present findings are in agreement with those of Singh *et al.* (2017) in mango, Gupta *et al.* (2022) in litchi, Tripathi and Kumar (2022) in mango, Saraswat *et al.* (2006) in litchi, Tripathi and Shukla (2008) in strawberry, Kumar *et al.* (2018) in mango, and Dubey *et al*. (2017) in strawberry, who also reported that the combined application of plant growth regulators and micronutrients significantly improved fruit yield and quality.

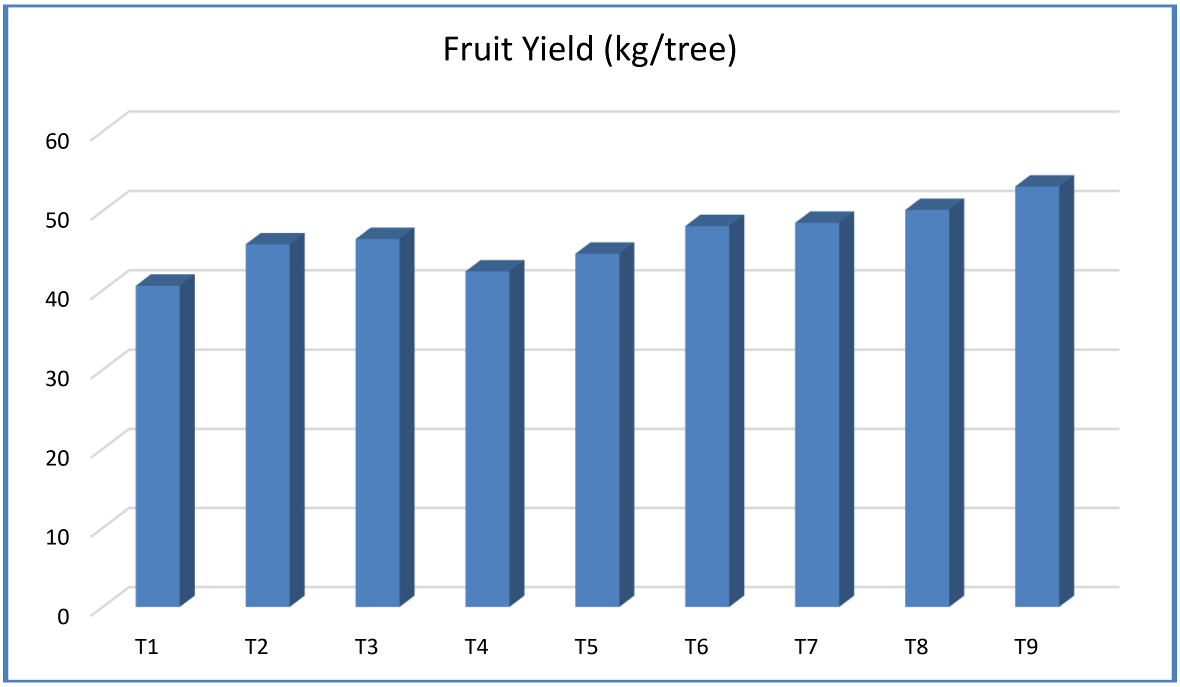

Fig. 1. Effect of GA_3 and $ZnSO_4$ on fruit yield (kg/tree)

4. Conclusion

The study showed that the combined foliar application of GA_3 and $ZnSO_4$ performed better than their individual applications for most measured fruiting, physical, biochemical and yield attributes of litchi cv. Rose Scented. Among the treatments, T_9 (GA_3 50 ppm + $ZnSO_4$ 1.0%) recorded the highest fruit retention at the pit-hardening and ripening stages, the lowest fruit cracking, the greatest fruit size and weight, the highest pulp: stone ratio, total sugar, TSS, sugar: acid ratio and fruit yield, together with the lowest titratable acidity. T_8 (GA_3 50 ppm + $ZnSO_4$ 0.5%) generally produced the next-best response. Under the conditions of this single-season experiment, a single foliar application of GA_3 at 50 ppm combined with $ZnSO_4$ at 1.0% after fruit set appears suitable for improving fruit retention, fruit quality and marketable yield of mature litchi cv. Rose Scented in the sub-tropical plains of Central Uttar Pradesh. The lower $ZnSO_4$ rate used in T_8 may also be considered where reduced zinc application is preferred.

5. Limitations

This study was conducted during a single cropping season on one litchi cultivar and at one location using mature trees. Consequently, the observed responses represent the specific cultivar, tree age and agro-climatic conditions evaluated. The experiment assessed a defined range of GA_3 and $ZnSO_4$ concentrations applied once after fruit set; therefore, inference beyond these treatment levels and application schedule should be made cautiously. Multi-season and multi-location evaluation would be useful for assessing the consistency of the observed treatment responses under varying environmental conditions.

Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. Grammarly and ChatGPT were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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