Influence of Tillage Practices and Microbial Consortia on Growth and Yield Performance of Chickpea (*Cicer arietinum* L.)

Abhishali[1], Sandeep Menon[2], Samprikta Priyadarshini[1], Ajeet Jakhad[1], Nachiketa[1]

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ABSTRACT

Background: Chickpea (*Cicer arietinum L.*) is a nutritionally rich *Rabi* pulse crop that significantly enhances biological nitrogen fixation and soil health in rainfed agroecosystems. The combined use of tillage methods and microbial consortia can significantly improve crop growth and resource-use efficiency.

Methods: A field experiment was executed in the *Rabi* season of 2024-2025 at the Agricultural Research Farm of Lovely Professional University, Phagwara, Punjab, India. The experiment was arranged in a split-plot design with three replications. Three types of tillage-zero tillage, minimum tillage and conventional tillage were used in the main plots and four types of microbial consortia treatments were used in the subplots: (i) seed treatment with microbial consortia @ 30 g kg^{-1} seed, (ii) soil application of consortia @ 2.5 kg mixed with 50 kg FYM ha^{-1}, (iii) combination of seed treatment and soil application and (iv) no consortia (control). Pearson correlation analysis and correlogram visualization were used to evaluate relationships among growth and yield attributes.

Result: Correlation analysis demonstrated a significant positive association between seed yield and plant dry weight (r = 0.997***), number of pods per plant (r = 0.997***) and seed index (r = 0.998***), underscoring their critical influence on chickpea productivity in rainfed environments. Yield attributes demonstrated robust positive interrelationships, indicating a coordinated contribution to yield formation. The correlogram showed clear clusters of biomass and yield components, with strong positive links between the most important growth and yield traits. Using integrated tillage management with microbial consortia application improved the relationship between growth and yield, which led to higher seed yield in chickpea. This study integrates tillage practices with microbial consortia and quantitatively assess their combined influence on growth-yield relationships in chickpea using correlation and correlogram analyses under rainfed semi-arid conditions.

Key words: Chickpea, Correlation, Microbial consortia, Rainfed agriculture, Tillage, Yield attributes.

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is a significant cool-season pulse crop grown in arid and semi-arid regions globally, owing to its adaptability to low-input conditions and satisfactory performance in rainfed environments. It plays an important role in food and nutritional security, especially in developing countries, because it is a good source of plant-based protein (18-22%), dietary fibre, vitamins and minerals like iron, zinc and calcium (Singh *et al.*, 2017; Yadav *et al.*, 2007). Chickpea is a primary source of protein and essential micronutrients in vegetarian diets (Merga and Haji, 2019).

In addition to nutritional benefits, chickpea contribute significantly to soil health and agroecosystem sustainability. It is a leguminous crop that improves the fertility of the soil by fixing nitrogen in a way that works with other organisms. This reduces dependence on synthetic nitrogen fertilizers. Growing chickpea also increases the activity of soil microbes, improves soil aggregation and makes the physical properties of soil better, thereby making it an essential component of sustainable cropping systems (Gaur *et al.*, 2012). Chickpea is one of the most important pulse crops in the world in terms of area and production. South Asia is the biggest producer (FAO, 2022).

India is the world's largest producer of chickpea, contributing about 45-50% of the total. This crop is mostly grown during the *Rabi* season, the yield potential is limited by unpredictable rainfall, terminal moisture stress, declining soil organic matter and poor crop management practices. Although India has the largest area under chickpea cultivation, but average yield remain well below the crop's genetic potential. This means that agronomic and soil management strategies need to be improved in right way. Integrated management strategies, combining both tillage and nutrient interventions, markedly enhanced

[1]Department of Agronomy, Lovely Professional University, Phagwara-144 411, Punjab, India.
[2]Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara-144 411, Punjab, India.

Corresponding Author: Abhishali, Department of Agronomy, Lovely Professional University, Phagwara-144 411, Punjab, India.
Email: abhishalithakur777@gmail.com

ORCIDs

0009-0009-3075-0156, 0000-0003-2128-3081, 0009-0007-0643-8563, 0009-0007-6392-3135, 0009-0002-3618-8220

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the relationships of yield-determining traits in field crops within analogous agro-ecological contexts (Jakhad *et al.*, 2025).

The soil's physical environment where crops grow is mostly determined by tillage practices. Zero tillage keeps residue on the surface of the soil, saves moisture and increases biological activity in the soil by lowering the oxidative breakdown of organic matter (Kassam *et al.*, 2019). An intermediate strategy is provided by minimum tillage, which lowers mechanical energy costs and soil erosion while preserving sufficient soil structure for root exploration. When used exclusively for extended periods of time, conventional tillage repeatedly disrupts soil aggregates, depletes soil organic carbon and reduces microbial community diversity, despite being effective for seedbed preparation and initial weed control (Priyadarshini *et al.*, 2025). In recent years, researchers have focused more on how tillage and biological inputs interact to affect chickpea yield.

Microbial consortia are an economical and environmentally beneficial way to improve crop productivity and nutrient use efficiency. Similar improvements in growth and yield attributes of chickpea under biofertilizer application have also been reported (Verma *et al.*, 2019). Numerous beneficial microorganisms, such as nitrogen-fixing bacteria (Azotobacter, Azospirillum), phosphate-solubilizing bacteria (PSB), potash-mobilizing bacteria (KMB) and plant growth-promoting rhizobacteria (PGPR), are integrated into a microbial consortium. These microorganisms work in concert to enhance nutrient uptake, root architecture and stress tolerance (Sathya *et al.*, 2024; Abhishali *et al.*, 2025). It has been shown that inoculating chickpea with microbial consortia improves nodulation, nitrogen fixation efficiency, biomass accumulation and eventually grain yield in field (Gopalakrishnan *et al.*, 2022; Karthika *et al.*, 2024).

Crop performance, microbial activity and nutrient dynamics are influenced by the complex soil environment created by the interplay of tillage techniques and microbial consortia application. The agronomic advantages of microbial inoculation may be increased under conservation tillage because better soil pore structure and moisture retention provide a more favorable microhabitat for introduced beneficial microorganisms. Developing integrated soil-crop management recommendations that are both economically and ecologically sound requires an understanding of these interactions.

In chickpea, yield is a polygenic trait that arises from the interplay of several growth and yield characteristics. In order to guide the selection of characters that contribute to yield, correlation analysis offers a statistical foundation for measuring the degree and direction of associations among these traits (Bello *et al.*, 2012). Rapid identification of trait clusters and variable groupings is made possible by correlogram analysis, which displays the complete correlation matrix visually through color-coded matrices (Graffelman and Leeuw, 2023; Nachiketa *et al.*, 2025). In order to understand the growth-yield dynamics of legume crops, agronomic research is increasingly using these tools together.

Despite several independent studies on the effects of tillage practices and microbial consortium on chickpea productivity, their combined influence on the interrelationships among growth and yield traits remains poorly understood, particularly under rainfed semi-arid conditions of the Indo-Gangetic plains. Furthermore, limited research has applied correlation and correlogram analyses to identify key yield-determining traits under integrated tillage and microbial management. Addressing this knowledge gap, it is essential to develop holistic and sustainable agronomic recommendations for chickpea cultivation. Therefore, the present study was conducted to evaluate the combined effects of tillage practices and microbial consortia on growth and yield attributes of chickpea and to analyze their interrelationships using correlation and correlogram approaches.

MATERIALS AND METHODS

Experimental site and climate

In the *Rabi* season of 2024-2025, the field experiment was carried out at the Lovely Professional University research farm in Phagwara, Punjab, India (31°14′ 43″ N″, 75°42′ 00′ E; 252 m above mean sea level). The experimental site is located in Punjab's central plain zone, which has a subtropical climate with hot summer, cold winter and moderate rainfall (an average of 711 mm per year). The experimental site's soil had a sandy loam texture, sufficient drainage and fertility for growing chickpea.

Experimental design and treatments

The experiment was laid out in a split-plot design with three replications, resulting in twelve treatment combinations. Three tillage techniques were used in the main plots: zero tillage, which involves direct seeding without disturbing the soil and maintaining surface residue; minimum tillage, which involves breaking the topsoil crust with a single shallow pass using a disc harrow and conventional tillage, which involves two deep ploughings, two harrowings and planking. Four microbial consortia treatments were included in the sub-plots: seed treatment with consortia (30 g kg^{-1} seed), soil application (2.5 kg consortia mixed with 50 kg FYM ha^{-1}), seed treatment with consortia (30 g kg^{-1} seed) + soil application (2.5 kg consortia mixed with 50 kg FYM ha^{-1}) and no consortia (Control). Size of subplot was 5.0 m $\times$ 4.5 m (22.5 m^2), with 10 cm between plants and 30 cm between rows.

Crop variety and sowing

The crop was sown at a seed rate of 80 kg ha^{-1} using the variety Pusa 362, which has moderate drought tolerance. To ensure accurate germination and crop establishment, seeds were manually sown on lines with a row spacing of

30 cm and an interplant spacing of 10 cm. The seeds were placed at a depth of 5 to 6 cm. Thirty minutes before seeding, seeds were thoroughly coated with the consortium slurry and shade-dried to maintain their viability as part of a microbial seed treatment.

Microbial consortia description

The experiment was conducted using a commercial lyophilized biofertilizer formulation (Katyayani NPK Microbial Consortia, Katyayani Organics Pvt. Ltd., India). With a minimum total viable count of 1×10^9 CFU g^{-1}, the product included a mixture of nitrogen-fixing bacteria (Azotobacter/ Azospirillum at 1×10^9 CFU g^{-1}), phosphate-solubilizing bacteria (1×10^9 CFU g^{-1}), potash-mobilizing bacteria (1×10^9 CFU g^{-1}) and silica-solubilizing bacteria (2×10^7 CFU g^{-1}).

Observations recorded

At 30, 60, 90, 120 DAS and harvest, growth parameters such as plant height (cm) and plant dry weight (g $plant^{-1}$) were measured. At 60 DAS, the number of nodules per plant were noted. The number of pods per plant, number of grains per pod, 100-seed weight (seed index, g), seed yield (kg ha^{-1}) and stover yield (kg ha^{-1}) were all measured with five randomly tagged plants per plot, which were uprooted at physiological maturity. Net plot harvest was used to estimate grain and straw yields per hectare. In order to analyze the physical, chemical and microbiological characteristics of the soil using conventional analytical techniques, soil samples were taken both before and after harvest.

Statistical analysis

CVSTAT statistical software was used to analyze data on all crop growth and yield parameters. The least significant difference (LSD) test was used to compare treatment means at the 5% probability level. To evaluate the accuracy of the experiment, the coefficient of variation (CV) was calculated. Using data collected from all treatments, Pearson correlation coefficients were calculated for each paired combination of growth and yield traits. The interpretation of correlation strength followed standard statistical guidelines (Schober *et al.*, 2018 and Mukaka *et al.*, 2012). Using corrplot-type analysis, a correlogram visualization was created to show the entire correlation matrix, with significance symbols signifying statistical significance and color gradient intensity denoting the correlation's magnitude.

RESULTS AND DISCUSSION

Table 1 displays the Pearson correlation coefficients for eight chickpea growth and yield characteristics across all treatment combinations. Table 2 provides the corresponding matrix of p-values. The entire correlation matrix is shown graphically by the correlogram (Fig 1). The majority of trait pairs in the current study showed highly significant positive

Table 1: Pearson correlation coefficients among growth and yield traits of chickpea (n=12).

Trait	Plant height	Dry weight	Nodules $plant^{-1}$	Pods $plant^{-1}$	Grains pod^{-1}	Seed index	Seed yield	Stover yield
Plant height	1	0.998***	0.990***	0.997***	0.852*	0.998***	0.996***	0.990***
Dry weight	0.998***	1	0.996***	0.999***	0.863*	0.997***	0.997***	0.987***
Nodules $plant^{-1}$	0.990***	0.996***	1	0.995***	0.898**	0.989***	0.993***	0.975***
Pods $plant^{-1}$	0.997***	0.999***	0.995***	1	0.858*	0.998***	0.997***	0.984***
Grains pod^{-1}	0.852*	0.863*	0.898**	0.858*	1	0.837*	0.856*	0.803*
Seed index	0.998***	0.997***	0.989***	0.998***	0.837*	1	0.998***	0.992***
Seed yield	0.996***	0.997***	0.993***	0.997***	0.856*	0.998***	1	0.991***
Stover yield	0.990***	0.987***	0.975***	0.984***	0.803*	0.992***	0.991***	1

***p<0.001 (two- tailed) **p<0.01 *p<0.05 Diagonal cells (-) represent self-correlation.

Table 2: Matrix of p-values associated with pearson correlation coefficients (Table 1).

Trait	Plant height	Dry weight	Nodules $plant^{-1}$	Pods $plant^{-1}$	Grains pod^{-1}	Seed index	Seed yield	Stover yield
Plant height	-	<0.001	<0.001	<0.001	0.015	<0.001	<0.001	<0.001
Dry weight	<0.001	-	<0.001	<0.001	0.012	<0.001	<0.001	<0.001
Nodules $plant^{-1}$	<0.001	<0.001	-	<0.001	0.006	<0.001	<0.001	<0.001
Pods $plant^{-1}$	<0.001	<0.001	<0.001	-	0.014	<0.001	<0.001	<0.001
Grains pod^{-1}	0.015	0.012	0.006	0.014	-	0.019	0.014	0.030
Seed index	<0.001	<0.001	<0.001	<0.001	0.019	-	<0.001	<0.001
Seed yield	<0.001	<0.001	<0.001	<0.001	0.014	<0.001	-	<0.001
Stover yield	<0.001	<0.001	<0.001	<0.001	0.030	<0.001	<0.001	-

Values <0.001 are shown as <0.001. Diagonal cells (-) are not applicable.

correlations ($p<0.001$), suggesting a strong co-regulatory basis for chickpea vegetative growth and reproductive development under the prescribed management practices.

Plant height

Plant height exhibited a highly significant and positive correlation with dry weight (r = 0.998***), nodules plant^{-1} (r = 0.990***), pods plant^{-1} (r = 0.997***), seed index (r = 0.998***), seed yield (r = 0.996***) and stover yield (r = 0.990***). This strong association between plant height and all major yield attributes indicates that taller plants have higher apical dominance and metabolic activity, which translates into better light interception, photosynthetic carbon gain and greater assimilate supply for reproductive sink organs, indicating that plant height is closely associated with yield (Karthika *et al.*, 2024 and Abdalla and Singh, 2025). The significant positive correlation observed between plant height and nodules plant^{-1} (r = 0.990***) further highlights the biological interdependence between vegetative growth and symbiotic nitrogen fixation in chickpea. Taller and more vigorous plants generally develop a larger and more active root system, which provides a greater surface area for rhizobial colonization and subsequent nodule formation. Enhanced nodulation increases biological nitrogen fixation (BNF), thereby supplying a greater amount of reduced nitrogen required for chlorophyll biosynthesis, leaf area expansion, protein synthesis and sustained vegetative growth. This creates a positive feedback mechanism between plant growth and nodulation, ultimately leading to improved reproductive development and yield performance under conventional tillage and microbial consortium management practices (Sathya *et al.*, 2024 and Wanjofu *et al.*, 2022).

Dry weight

Dry weight showed highly significant positive correlations with pods plant^{-1} (r = 0.999***), seed yield (r = 0.997***), seed index (r = 0.997***) and stover yield (r = 0.987***). The remarkably high correlation (r = 0.999***) between dry weight and pods plant^{-1} indicates that biomass accumulation is the main factor influencing chickpea reproductive sink capacity. The main carbon substrate for pod and seed filling is dry matter, which is accumulated by plants with larger leaf areas and higher photosynthetic rates (Gopalakrishnan *et al.*, 2022). These results are in line with those of Karthika *et al.* (2024); Sathya *et al.* (2024), who found that chickpea under various fertilizer and biofertilizer regimes had positive dry matter-yield relationships. The findings highlight the significance of management techniques that optimize early-season biomass accumulation, such as tillage and microbial consortia, as a means of enhancing final grain yield.

Nodules plant^{-1}

Nodules per plant showed highly significant positive correlations with plant height (r= 0.990***), dry weight

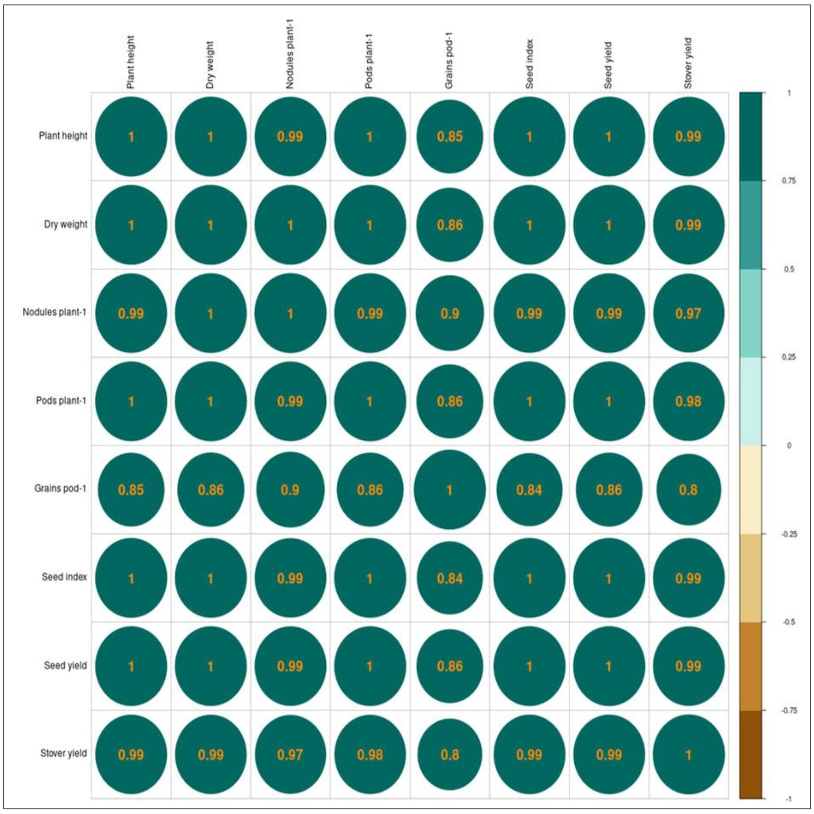

Fig 1: Correlogram analysis of growth and yield parameters in chickpea.

(r = 0.996***), pods per plant (r = 0.995***), seed yield (r = 0.993***) and stover yield (r = 0.975***). The high correlation coefficients verify that one of the key mechanisms by which the application of microbial consortia results in increased crop productivity is enhanced biological nitrogen fixation (BNF) through nodulation. Increased nodulation under biofertilizer application significantly improved growth and yield traits in chickpea, with biofertilizer-enhanced nodulation contributing 40-60 kg N ha^{-1} through BNF, thereby reducing dependence on synthetic nitrogen inputs. Nodules serve as the main site of symbiotic nitrogen acquisition, providing reduced nitrogen for leaf chlorophyll synthesis, enzymatic processes and protein deposition in seeds (Sathya *et al.*, 2024; Wanjofu *et al.*, 2022).

Pods plant^{-1}

Pods per plant exhibited the strongest positive correlation with dry weight (r = 0.999***) among all trait pairs and highly significant correlations with plant height (r = 0.997***), seed index (r = 0.998***), seed yield (r = 0.997***) and stover yield (r = 0.984***). In accordance with the known function of pods per plant as a primary yield sink in determinate legume species, this finding identifies pods per plant as the single most important yield-determining characteristic in this study (Bello *et al.*, 2012). The nearly perfect linear relationship between pods plant^{-1} and dry weight (r = 0.999***) indicates that pod load capacity is nearly entirely influenced by carbon supply (dry weight) and that any management strategy whether tillage-based moisture conservation or microbial enhancement of nutrient supply will correspondingly increase pod number.

Grains pod^{-1}

Grains pod^{-1} exhibited moderate but statistically significant positive correlations with plant height (r = 0.852*), dry weight (r = 0.863*), nodules plant^{-1} (r = 0.898**) and seed yield (r = 0.856*). Grains per pod is a trait with higher genetic determination and lower phenotypic plasticity in response to management practices, so the relatively lower correlation values for this trait in comparison to other yield components are expected. Compared to pod number or biomass accumulation, the trait is mainly governed by floral architecture and embryo development processes, which are less susceptible to environmental changes (Abdalla and Singh, 2025). However, the strong positive correlation with nodulation (r = 0.898**) implies that sufficient nitrogen supply via BNF lowers flower and pod abortion, supporting increased grain set per pod under enhanced microbial activity.

Seed index (100-seed weight)

Seed index showed highly significant positive correlations with plant height (r = 0.998***), pods per plant (r = 0.998***), seed yield (r = 0.998***) and stover yield (r = 0.992***). The 100-seed weight is a reliable integrative indicator of overall crop performance in this experiment, as evidenced by the consistently high correlation of seed index with all significant growth and yield variables. During the grain-filling phase, heavier seeds indicate effective assimilate partitioning to seed sinks, which is made possible by sufficient photosynthetically active radiation interception, increased leaf area duration and continuous source-sink flux of carbon and nitrogen (Gopalakrishnan *et al.*, 2022).

Seed yield

Seed yield showed highly significant positive correlations with plant height (r = 0.996***), dry weight (r = 0.997***), nodules plant^{-1} (r = 0.993***), pods plant^{-1} (r = 0.997***) and seed index (r = 0.998**)*. The strongest direct predictors of seed yield among these were pods plant^{-1} (r = 0.997***) and seed index (r = 0.998), indicating that in order to maximize grain yield, management interventions should simultaneously target pod production and individual seed weight. The current findings are consistent with those of Abdalla and Singh (2025); Bello *et al.* (2012), who found that under integrated agronomic management, both individual seed size and reproductive output are important factors influencing chickpea productivity.

Stover yield

Stover yield exhibited significant positive correlations with plant height (r = 0.990***), dry weight (r = 0.987***), pods per plant (r = 0.984***), seed index (r = 0.992***) and seed yield (r = 0.991***). A coordinated pattern of above-ground biomass allocation is indicated by the strong positive correlation (r = 0.991***) between seed yield and stover yield: management strategies that increased grain production also increased total biological yield. This supports the multipurpose value of integrated tillage and biofertilizer management in chickpea-based cropping systems and has significant implications for crop residue availability for soil mulching, livestock feed, or organic matter incorporation (Merga and Haji, 2019) reported similar outcomes from rainfed chickpea experiments.

Correlogram interpretation

The correlogram provides a visual representation of interrelationships among traits, facilitating easier interpretation of complex correlation structures (Graffelman and Leeuw, 2023). The patterns observed in the numerical correlation matrix were further validated through the correlogram (Fig 1). A tight positive cluster with deep blue color coding (r > 0.990) was formed by six traits: Plant height, dry weight, nodules plant^{-1}, pods plant^{-1}, seed index and seed yield. This showed nearly perfect crossover between biomass and reproductive components. The position of grains pod^{-1} in the cluster was lateral, indicating that their correlations with the core cluster were somewhat lower but still significantly positive. The visual clustering pattern confirms that, in rainfed conditions, integrated management of tillage and microbial consortia act holistically to simultaneously improve all major determinants of seed yield rather than isolated components, resulting in synergistic yield enhancement in chickpea. The relatively high correlation coefficients observed in the present study may be influenced by the limited number of treatment combinations (n=12), which can lead to an overestimation of correlation strength (Singh *et al.*, 2024). However, the consistency and biological plausibility of the associations among key growth and yield traits suggest that these relationships are meaningful and agronomically relevant.

CONCLUSION

The current study shows that under rainfed conditions, the growth and yield characteristics of chickpea (*Cicer arietinum* L.) are greatly enhanced by the combined application of appropriate tillage techniques and microbial consortia delivered through both seed treatment and soil application. The most important characteristics that determine yield are pods per plant, seed index and dry weight, all of which have nearly perfect positive correlations with seed yield. Nodules per plant demonstrated a strong positive correlation with all major yield attributes, indicating that one of the main mechanisms promoting yield improvement under this management system is biological nitrogen fixation, which is enhanced by microbial consortia. Plant height, dry weight, nodules, pods, seed index and seed yield were found to form a tight trait cluster in the correlogram visualization, demonstrating their coordinated contribution to productivity. These results imply that the best breeding and management practices for increasing chickpea productivity in semi-arid rainfed environments will focus on simultaneously improving biomass accumulation, nodulation and pod production. Integrated use of tillage practices along with microbial consortia is recommended for improving chickpea productivity.

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Conflict of interest

The authors declare no conflict of interest related to the publication of this research paper.

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