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ASSESSMENT OF THE SOIL IMPROVEMENT ABILITY OF MULTIFUNCTIONAL BIOLOGICAL PRODUCTS ON POOR SOIL USED FOR PEANUTS (*ARACHIS HYPOGAEA* L.) IN QUANG TRI PROVINCE

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Abstract: Peanuts have emerged as a vital crop in Quang Tri province, serving as a primary income source for numerous farmers. Combining organic fertilizers and agricultural by-products with beneficial microbial preparations enhances soil quality and improves agricultural efficiency. Applying 5 kg/ha of a multifunctional biological soil conditioner in the fertilization and care process for peanuts in Quang Tri province raises soil acidity (pHKCl) from 3.97 to 4.67. Organic carbon content (OC%) increases from 2.78% to 6.89%, while the concentrations of readily available phosphorus and potassium rise from 197.52 mg/100 g and 206.68 mg/100g to 439.53 mg/100 g and 511.60 mg/100 g, respectively. Calcium content increases from 7.73 Idl/100 g to 8.76 Idl/100 g, and magnesium content rises from 1.55 Idl/100 g to

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2.42 Idl/100 g. Notably, the density of beneficial microorganisms, nitrogen-fixing bacteria, phosphate-solubilizing bacteria, and cellulose-decomposing microorganisms all increase after four months, with respective rises from 1.92 x 10^6, 2.64 x 10^5, 4.48 x 10^5, 3.55 x 10^5 to 6.86 x 10^6, 1.45 x 10^6, 2.04 x 10^6 and 1,71x106. The profit is 54,870,000 VND, achieving a return on investment of 1.61 times.

Keywords: *Peanut plant, microbial formulations, poor soil, soil improvement.*

1. INTRODUCTION

Peanuts have long been recognized as a key crop in Quang Tri Province, serving as a primary income source for numerous farmers. However, excessive use of fertilizers and chemical pesticides has led to the accumulation of harmful substances in the environment, leaving residues on agricultural products and in the soil. This contamination poses direct health risks to both producers and consumers and contributes to the ongoing degradation of arable land. Thus, advancing research and applications of microbial products containing beneficial microorganisms is essential, as these can enhance soil quality, support healthy plant growth, reduce pests and diseases, and increase crop yields. Integrating crop and soil management with biotechnological products and methods underscores the critical role of soil biological processes. The addition of microbial strains and organic matter mixtures into the soil fosters the establishment of beneficial microbial communities, thereby aiding in soil remediation, enhancing soil health, improving crop performance, and reducing environmental impact [1]. Consequently, the utilization of microbial products to process organic waste and agricultural by-products for fertilizers and soil improvement, alongside pest control and yield enhancement, has been the focus of research and application by various scholars [2-6]. Numerous studies in biotechnology have demonstrated that root-associated microorganisms and endophytes effectively restore the biological health of agricultural soils [3,7,8]. Notably, combining these with biotechnological products containing nitrogen-fixing microbes, phosphate-solubilizing bacteria, plant growth-promoting rhizobacteria, or pest-suppressing microorganisms provides significant advantages for soil management and crop productivity [9].

This paper presents some research results on the application of multifunctional biological products for improving degraded soil used for peanuts in Quang Tri Province.

2. MATERIALS AND METHODS

2.1. Sample collection

The biological products developed for soil improvement consist of various beneficial microbial strains. These include three bacterial strains: *Bacillus subtilis* TiN1, *Bacillus megaterium* CFB3, and *Bacillus flexus* Ti6; two fungal strains such as *Penicillium oxalicum* N19CL and *Trichoderma harzianum* N4.1; and one actinobacterial strain as *Streptomyces diastatochromogenes* CLĐ XK3. These strains were developed as part of the pilot production projects VAST.NĐP.14/12-13, VAST.SXTN.04/15-16, and KHCN-TN3/11-15. Additionally, two bacterial strains, *Nitrosomonas winogradski* NBRC 14297 and *Azotobacter chroococcum* NBRC 102613, were produced using submerged and surface fermentation technologies at the Quang Tri Research, Technology Transfer, and Innovation Center. The project employs the peanut cultivar Sen Lai and utilizes a method of composting agricultural by-products with selected microorganisms to produce microbial organic fertilizer. The research and application of these techniques are scheduled from January 2024 to May 2024.

2.2. Fertilization and care process

The fertilization and care process involves applying soil improvement products made from well-rotted manure and organic agricultural waste or by-products, prepared 45 days in advance. The full amount of lime is applied 7-10 days before tilling the soil to optimize its effectiveness.

Table 1. The experimental models are calculated based on a unit of 1 hectare

Models	Soil improvement products (kg)	WRM + OAWBP (Ton)	N (kg)	P (kg)	K (kg)	Lime (kg)	IMO (liter)
MH1	0	5	120	540	160	500	-
MH2	5	5	0	0	0	250	*IMO

Note: MH1: traditional local model for caring for and fertilizing peanuts; MH 2: Organic care and fertilization model using multifunctional biological products for soil improvement in peanut cultivation; WRM: Well-rotted manure; OAWBP: organic agricultural waste, by-products

MH1:

Base fertilization: the entire amount of superphosphate; half of the well-rotted manure; half of the urea; and half of the potassium chloride. Create furrows, mix all the fertilizers with the topsoil, then sow the seeds and cover them.

Top dressing: First top dressing: 15 days after planting with ¼ of the total amount of superphosphate, ¼ urea, and ¼ potassium chloride; Second top dressing: 30 days after planting, apply the remaining amount of fertilizer.

MH2:

Base fertilization:1/2 of the soil improvement products have been mixed with Well-rotted manure and organic agricultural waste, by-products

Top dressing: First top dressing: 15 days after sowing, apply 1/4 of the total amount of organic fertilizer mixed with the soil improvement products; second top dressing: 30 days after sowing, apply the remaining amount of organic fertilizer that has been mixed with the soil improvement products + apply between the rows. Prioritize agricultural by-products that are high in potassium and nitrogen, such as banana stems, banana flowers, banana peels, and soybean pods.

**IMO* (Indigenous Microorganism) is purchased from Đức Bình Biotechnology Co., Ltd: 1 liter of base IMO is diluted to make 10 liters of secondary IMO, then blended with 1 kg of materials such as fish or aloe vera, and fermented for 15 days before being filtered through 2 layers of mesh for use during the growth stage of stems and leaves. 1 liter of base IMO is diluted to make 10 liters of secondary IMO, which is then mixed with materials such as banana flowers and banana fruits, fermented for 15 days, and then diluted with 100 liters of water for foliar spraying and root irrigation during the flowering and fruit formation stages

Model layout: The experimental area of 5000 m^2 is divided into 2 parts corresponding to 2 application processes for 2 cropping models. Peanut rows are planted as outer protection and in the middle to protect both models (seeds are sown and allowed to grow naturally.

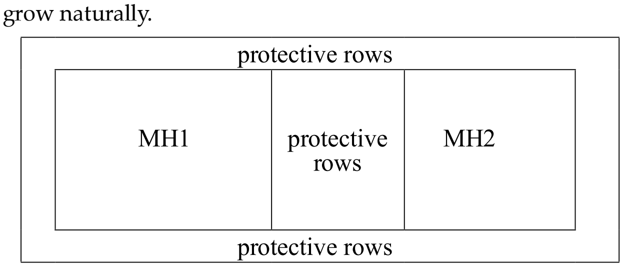


Figure 1. Experimental layout diagram

2.3. Indicators and monitoring methods

Monitoring indicators:

Monitoring indicators include soil chemical properties (pH_{KCl}, N_{ts} (total nitrogen), P_2O_5ts (total phosphorus), K_2O_{ts} (total potassium), P_2O_{5dt} (available phosphorus content), K_2O_{dt} (available potassium content), OC% (organic carbon content), Ca^{++}, and Mg^{++}), beneficial microbial density (beneficial microorganisms, nitrogen-fixing microorganisms, phosphate-solubilizing microorganisms, cellulose-decomposing microorganisms), and peanut growth metrics such as plant height and yield components (number of effective flowers per plant, number of sound pods per plant, 100-pod weight in grams, theoretical yield, actual yield, and efficiency metrics like net profit, calculated as total revenue minus costs, and profit margin (Value Cost Ratio or VCR, where VCR = net income from product use/product cost)).

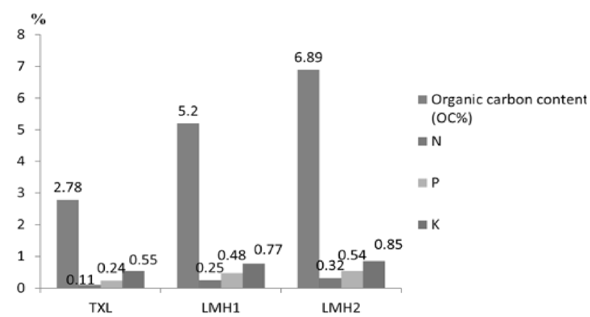
Research and analysis methods:

Research and analysis methods follow the National Technical Regulation on the evaluation of cultivation value and use of peanut varieties (QCVN 01-57:2011/BNNPTNT) for growth, development, and yield. Disease indicators are evaluated according to TCVN 13268-3:2021, Plant Protection - Method for Investigating Pest Organisms - Part 3: Industrial Crop Group. Soil pH_{KCl} is analyzed based on TCVN 5979:2007, total nitrogen (N%) as per TCVN 6498:1999, total phosphorus (P_2O_5 %) following TCVN 8940:2011, available phosphorus as per TCVN 8661:2011, total potassium (K_2O%) based on TCVN 8660:2011, available potassium per TCVN 8662:2011, organic carbon (OC%) based on TCVN 8941:2011, Ca^{2+} content as base on TCVN 8569:2010, and Mg^{2+} content based on TCVN 8569:2010. Beneficial microbial density is measured using TCVN 6167:1996, TCVN 6166:2002, TCVN 6167:1996, and TCVN 6168:2022 standards. Data processing is conducted using IRRSTAT 5.0 and Excel software.

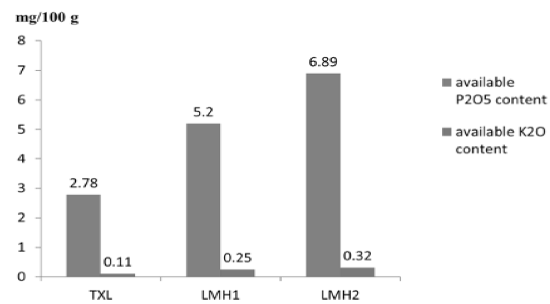
3. RESULTS

3.1. The impact of multifunctional biological products on soil chemical properties and microbial density in peanut cultivation on poor soil in Quang Tri Province

The results of analyzing some chemical indicators in the soil before and after applying biological products to improve the soil are shown in Table 2, Figures 2 and 3. The acidity level of the soil (pH_{KCl}) had small changes, the pH increased slightly after applying biological products to improve the soil. In the control model, the pH was 4.57, while in the model with the biological preparation, it increased to 4.67. Organic carbon content (OC%) significantly increased in model 2, reaching 6.89%, compared to 5.20% in model 1. Total nitrogen, phosphorus, and potassium (N%, P_2O_5, K_2O) were also increased in both models. Before applying biological products, the content of easily available P2O5 was 197.52 mg/100 g and the content of easily available K2O was 206.68 mg/100 g. After application, in model 2, the content of easily available P2O5 increased to 439.53 mg/100 g and the content of easily available K2O was 511.60 mg/100 g. Meanwhile, in model 1, these values were 377.54 mg/100 g and 496.67 mg/100 g, respectively, lower than in model 2. The content of Ca^{++} and Mg^{++} cations both increased in the two models after applying organic fertilizer and biological products to improve the soil. Before applying biological products to improve the soil, the Ca^{++} content was 7.73 Idl/100 g, increased to 8.03 Idl/100 g in model 1 and increased even more in model 2 to 8.76 Idl/100 g. The Mg^{++} content increased in model 1 to 1.84 Idl/100 g and in model 2 to 2.42 Idl/100 g. While the Mg^{++} content before applying biological products was from 1.55 Idl/100 g before treatment. Microbial density, including nitrogen-fixing bacteria, phosphate-solubilizing microorganisms, and cellulose-decomposing microbes, was higher after the application of fertilizers and biological preparations for soil improvement in both models compared to pre-application levels. In model 2, after four months of planting and caring for peanuts, the density of beneficial microorganisms was 7.24×10^7, the density of nitrogen-fixing microorganisms was 1.75×10^7, phosphate-dissolving microorganisms was 2.81×10^6 and cellulose-decomposing bacteria was 7.3×10^6. The densities of beneficial microorganisms were all lower than in model 2. Specifically, the density of beneficial microorganisms was 6.86×10^6, nitrogen-fixing microorganisms was 1.45×10^6, phosphate-dissolving microorganisms was 2.04×10^6 and cellulose-decomposing bacteria was 1.71×10^6.



Figures 2. The effect of multifunctional biological products for soil improvement on the organic carbon (OC), total nitrogen, phosphorus, and potassium content (%) for peanuts in 2024, Quang Tri



Figures 3. The effect of multifunctional biological products for soil improvement on the readily available P2O5 and K2O content for peanuts in 2024, Quang Tri

(Analysis results at the Quang Tri Center for Standards, Metrology, and Quality Control)

Table 2. The effect of multifunctional biological products for soil improvement on the chemical properties of the soil and microbial density in the soil in 2024, Quang Tri province

Models	pHKCl	Ca++ ldl/100g	Mg++ ldl/100g	Beneficial microbial density
DAT TXL	3.97	7.73	1.55	1.92x106
LMH1	4.57	8.03	1.84	6.86x106
LMH2	4.67	8.76	2.42	7.24x107
Models		**Nitrogen-fixing microbial density**	**Phosphate-solubilizing microbial density**	**Cellulose-decomposing microbial density**
DAT TXL		2.64x105	4.48x105	3.55x105
LMH1		1.45x106	2.04x106	1.71x106
LMH2		1.75x107	2.81x106	7.3x106

(Analysis results at the Quang Tri Center for Standards, Metrology, and Quality Control)

Note: DAT TXL: Soil samples of the model before fertilization; LMH1: Soil samples of model 1 after fertilization; LMH2: Soil samples of model 1 after fertilization

3.2. The effect of multifunctional biological products for soil improvement on the height of the main stem of peanuts

The height of peanut plants in both the control model and the model using biological products to improve soil increased during the growth and development of peanut plants. The plant height reached its maximum at harvest (Table 3). However, at each growth stage, the height of peanut plants varied between the two models, which followed different cultivation practices. At harvest, the average height of peanut plants in model 1 was 38.7 ± 0.78 cm, while model 2, which incorporated the use of multifunctional biological soil improvement products, achieved a higher average plant height of 46.3 ± 0.89 cm. This suggests that the application of soil-improving biological products in model 2 positively impacted peanut plant growth compared to Model 1.

Table 3. The effect of multifunctional biological products for soil improvement on the height of the main stem of peanut in 2024, Quang Tri province

Unit: cm

Models	First branch	Beginning of flowering	End of flowering	Harvest
MH1	5,6 ± 0,20	21,9 ± 0,31	32,6 ± 0,58	38,7 ± 0,78
MH2	5,8 ± 0,25	28,4 ± 0,47	37,1 ± 0,81	46,3 ± 0,89

3.3. The effect of multifunctional biological products for soil improvement on the flowering of peanuts

The data in Table 4 demonstrate that the application of multifunctional biological products for soil improvement results in no difference between the two models regarding total flowering duration and the number of peak flowering periods in peanuts. Both models exhibit a consistent flowering period of 24 days and two peak flowering times. However, differences are observed in the total number of flowers produced per plant and in the effective flower rate, suggesting that these biological products influence flower productivity and quality.

In model MH1, the total number of flowers per plant reached an average of 50.9 flowers, while model 2 showed a slightly higher average of 52.7 flowers per plant, indicating a positive effect on flower production with the second fertilization process. Moreover, the effective flower rate, which measures the percentage of flowers that are viable and contribute to crop productivity, was notably different between the models. Model MH1 displayed an effective flower rate of 20.8%, whereas model MH2 achieved a higher rate of 24.1%. This increase in effective flower rate in model 2 suggests that the fertilization method used in this model may enhance flower viability and, potentially, yield outcomes.

Overall, these results highlight that while flowering duration and peak flowering frequency are unaffected by the fertilization methods, the total number of flowers and the effective flower rate is improved with the approach used in model MH2, reflecting the potential of biological products in supporting flower development and effectiveness.

Table 4. The effect of multifunctional biological products for soil improvement on the flowering of peanuts in 2024, Quang Tri province

Models	Total flowering duration (days)	Number of peak flowering periods (periods)	Total number of flowers/plants (flowers)	Effective flower rate (%)
MH1	24	2	50.9±2.1	20.8
MH2	24	2	52.7±1.8	24.1

3.4. The effect of multifunctional biological products for soil improvement on yield components and peanut yield

The results presented in Table 5 indicate that both fertilization models influence several yield components, including the total number of pods per plant, the number of sound pods per plant, the weight of 100 pods, theoretical yield, and actual yield.

Table 5. The effect of multifunctional biological products for soil improvement on yield components and peanut yield in 2024, Quang Tri province

Models	Total number of pods/ plant (pods)	Number of sound pods/ plant (pods)	P100 pods (g)	Theoretical yield (tonnes/ha)	actual yield (tonnes/ha)
MH1	21.2±1.3	10.6±1.2	143.9±6.2	37.75	22.72
MH2	29.6±3.3	12.7±1.3	152.2±4.4	47.84	27.78

In particular, the weight of 100 pods appears to be a critical factor in determining the yield potential of each model. The weight of 100 pods of the biological product application model was 152.2 grams, higher than the control model of 143.9 grams. This suggests an enhancement in pod quality when using the fertilization method applied in model 2. Correspondingly, the theoretical yield for model 1 is calculated at 37.75 tons per hectare, whereas model 2 demonstrates a significantly higher theoretical yield of 47.84 tons per hectare, reflecting the positive impact of the soil improvement products.

The actual yield, which is an essential indicator of the practical effectiveness of fertilization and soil enhancement practices, further supports these findings. Model 1 achieved an actual yield of 22.72 tons per hectare, while Model 2 attained an even greater yield of 27.78 tons per hectare, representing a 22% increase. This increase highlights the potential of Model 2's fertilization approach to enhance peanut productivity through improved pod formation and weight.

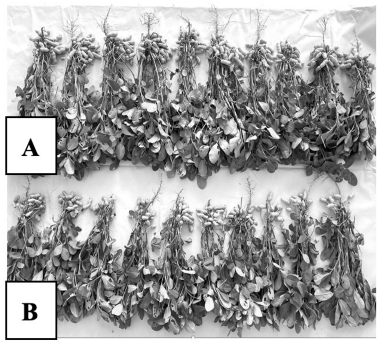


Figure 4. Peanuts harvested from the widespread model in 2024 in Quang Tri Province (A) Peanuts harvested from the model applying multifunctional biological products for soil improvement (B) Peanuts harvested from the model cultivated according to the local farmers' practices

3.5. Economic efficiency of multifunctional biological products for soil improvement on poor soil used for peanuts

Assessing the effectiveness of applying biological products for crops in general and the Sen Lai peanut variety, in particular, is essential for evaluating economic efficiency.

Table 6. Economic efficiency of multifunctional biological products for soil improvement on poor soil used for peanuts (Arachis hypogaea l.) in Quang Tri province

Indicators	MH1 (VND/ha)	MH2 (VND/ha)
Investment costs	47,161,000	34,026,000
Total revenue	72,704,000	88,896,000
Net profit	25,543,000	54,870,000
Value cost ratio	0.54	1.61

Note: Economic efficiency = Net profit

The data in Table 6 reveal that model 2 achieved a higher yield of 27.78 tons per hectare, which translated to significantly increased total revenue and profit compared to model 1. The value-cost ratio (VCR) further underscores the economic advantage of model 2. While model 1 has a VCR of 0.54, model 2 demonstrates a VCR of 1.61, indicating greater economic efficiency and profitability.

These results highlight that the application of organic fertilizers, in combination with multifunctional biological products for soil improvement as used in model 2, is a cost-effective and economically viable option for farmers, contributing to higher profitability and sustainability in agricultural practices. The Results section should describe the outcome of the study. This section may be divided by subheadings.

4. DISCUSSION

Advancements in biotechnology today, particularly in developing microbial products with beneficial microorganisms, are being applied in biological soil management. These products, fermented with organic fertilizers and agricultural by-products, are either added to the soil or applied directly to enhance soil improvement, restore soil health, and increase crop yields (Ayuj Dutta et al., 2024) [10].

In this study, the application of organic fertilizers fermented with decomposed manure and agricultural by-products has notably improved soil properties, specifically by increasing organic matter content, enhancing nitrogen levels, and boosting the density of beneficial soil microorganisms. Key microbial strains contributing to nitrogen fixation, such as *Bacillus megaterium* CFB3 and *Azotobacter chroococcum* NBRC 102613, as well as strains promoting rapid organic matter decomposition like *Trichoderma* *harzianum* N4.1 and *Nitrosomonas winogradski* NBRC 14297, have played a significant role. These microbial activities have led to a rise in organic carbon (OC) content in the peanut cultivation soil to 6.89%, up from 2.78% before treatment. Additionally, total nitrogen content increased from 0.11% to 0.32%. These findings align with previous studies on the potential of microbial organic fertilizers as alternatives to chemical fertilizers, as reported by Ken E. Giller et al. (1998), Nguyen Van Vien et al. (2012), and Nguyen Thu Ha et al. (2016) [4,11,12].

Additionally, the biological products in this study contain *Bacillus subtilis* TiN1 and *Penicillium oxalicum* N19CL, which have phosphate-solubilizing activity. When applied in model 2, they increased the P_2O_5 content from 197.52 mg/100g has increased 439.53 mg/100g. Many types of microorganisms have been shown to play a crucial role in the biogeochemical cycling of both inorganic and organic phosphorus in the soil around plant roots. Therefore, the rapid commercial development of phosphate-solubilizing microbial products is anticipated in the future, as previously reported by Parnell et al. (2016), Rafi et al. (2019), and Hui-Ping et al. (2023) [13-15].

The growth correlation between the stem, leaves, and root system in plants has been defined by botanists as a stimulatory relationship. Studies have shown that if the stem and leaves grow well, it will lead to better root growth and higher yields, and vice versa [16]. The results of this study indicate that the model utilizing multifunctional biological products for soil improvement, when supplemented with beneficial microbial strains, has led to increased height of peanut plants, a higher number of effective flowers, an increased total number of pods per plant, a greater number of sound pods, and an enhanced weight of 100 pods, ultimately resulting in a 22% increase in yield.

The results of this study also show that the model applying multifunctional biological products for soil improvement, supplemented with beneficial microbial strains, has supported increased height of peanut plants, enhanced the number of effective flowers, increased the total number of pods per plant, boosted the number of sound pods, and raised the weight of 100 pods, leading to a 22% increase in yield. Earlier, a study by Nguyen Thu Ha et al. (2016) [4] using microbial products on peanuts grown in coastal sandy soils in Nghe An and Binh Dinh provinces resulted in yield increases of 16.1% to 18.2%.

By understanding and managing the interactions between soil, plants, and beneficial microorganisms, biotechnology offers effective tools to enhance soil fertility, reduce environmental impact, and promote the goals of sustainable agriculture.

5. CONCLUSIONS

The application of 5 kg/ha of multifunctional biological products for soil improvement in the fertilization and care process of peanuts in Quang Tri Province has resulted in an increase in soil acidity (pH_{KCl}) from 3.97 to 4.67; the organic carbon content (OC%) increased from 2.78% to 6.89%. The available phosphorus and potassium contents, initially at 197.52 mg/100g and 206.68 mg/100g, respectively, increased to 439.53 mg/100g and 511.60 mg/100g. The calcium content (Ca^{++}) rose from 7.73 Idl/100g to 8.76 Idl/100g, and magnesium (Mg^{++}) increased from 1.55 Idl/100g to 2.42 Idl/100g. Notably, the density of beneficial microorganisms, nitrogen-fixing microorganisms, phosphate-solubilizing microorganisms, and cellulose-decomposing microorganisms all increased after 4 months of fertilization, rising from $1,92x10^6$, $2,64x10^5$, $4,48x10^5$, $3,55x10^5$ to $6,86x10^6$, $1,45x10^6$, $2,04x10^6$ và $1,71x10^6$, respectively. This supports a 22% increase in peanut yield, with a profit of 54,870,000 VND achieving a profit margin of 1.61 times.

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Conflicts of Interest: The authors declare no conflict of interest.

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