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Probiotics and Postbiotics from Southeast Asian Traditional Fermented Foods Highlight Functional Potential in Malaysia

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Abstract

Fermented foods are essential in Southeast Asia's culinary and cultural landscapes, providing nutrition, preservation, and microbial diversity. Beyond their traditional significance, these foods include beneficial probiotics and metabolic by-products, known as postbiotics, that improve food functionality and human health. This review compiles recent research on the probiotic diversity and postbiotic potential of fermented foods from Southeast Asia, with a focus on traditional Malaysian variations such as *budu, tempoyak, belacan, cincalok, tapai, pekasam,* and pickled *maman*. It covers the most common microbial species, fermentation substrates, and bioactive metabolites in the fermented foods, while also highlighting recently discovered postbiotic components such as exopolysaccharides, peptides, and short-chain fatty acids. Despite these advantages, Malaysian traditional fermented foods have received minimal research, particularly in metabolomic characterization and clinical validation. Omics tools integration, safety assessment, and the valuation of local probiotic strains for functional food innovation will be beneficial in the next steps for fermentation science in Malaysia.

INTRODUCTION

One of the earliest biotechnology developments in human history, fermentation offers a sustainable means of food preservation, flavor enhancement, and nutritional enrichment. Southeast Asian food systems have a long history of fermentation, which is impacted by raw ingredients, cultural preferences, and environmental conditions. The tropical climate of the region fosters spontaneous fermentation processes dominated by *Bacillus* species, yeasts, and lactic acid bacteria (LAB). They enhance the sensory quality of food, as well as supporting gastrointestinal health, immunological modulation, and metabolic balance [1]. Recently, the probiotic and postbiotic potential of traditional fermented foods, which extends beyond flavor and preservation to health-promoting functionality, has gained scientific attention. Probiotics are living bacteria that provide health benefits when given in sufficient doses [2]. They are naturally present in many fermented foods from Southeast Asia. On the other hand, postbiotics are gaining more attention as more stable and safer substitutes for living probiotics. Postbiotics are non-living microbial metabolites or cell components that provide physiological advantages [3].

With its diverse cuisine and thriving wildlife, Malaysia is a microcosm of the ample variety of Southeast Asia's fermented foods. Regional delicacies such as *tempoyak* (fermented durian), *budu* (fermented anchovy sauce), and *tapai* (fermented glutinous rice) are usually eaten by local communities in daily life or during festivities like weddings.

These fermented foods are found to contain complex microbial populations that support fermentation and generate health-promoting compounds [4–6]. However, most people are not aware about their health benefits, because little is known about the microbiological and functional constituents of the microorganisms. This review discusses the latest research on the probiotics and postbiotics associated with Southeast Asian fermented food products, focusing on Malaysian traditional fermented foods. Additionally, this study proposes research directions for the identification of bioactive components and understudied microbial strains.

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Background of fermented foods in Southeast Asia

Diversity of Southeast Asian fermented foods

Southeast Asia boasts an wide variety of fermented foods that have been long consumed since centuries ago. Common substrates in this region include fish (*budu, cincalok*), legumes (*tempeh, taucu*), fruits (*tempoyak*, pickled *mango*), cereals (*tapai, basi* rice wine), and vegetables (pickled *maman, asam rebus*) [1]. Microorganisms such as yeasts, LAB, and other bacterial species undergo metabolic activity during the fermentation process. They ferment carbohydrates and other substrates to generate metabolites including alcohols, organic acids, gases, and bioactive components. Simultaneously, these microorganisms help to inhibit spoilage bacteria in the foods, while altering the textures, flavors, and chemical qualities of the foods. This shows fermentation process fosters the production of beneficial metabolites, and improves nutritional value, safety, and sensory qualities in the food products [7].

Several fermentation methods can be used to make fermented food products, as shown in **Table 1**. Lactic acid fermentation is commonly involved in fermentations of dairy, vegetables, and cereals, and carried out by LAB species like *Lactobacillus, Leuconostoc*, and *Pediococcus*. Yeasts, such as *Saccharomyces* spp., mediate the alcoholic fermentation of wines, beers, and rice wines. Spontaneous fermentation uses native microbial populations available from raw materials and the environment, while controlled fermentation uses starter cultures to get consistent results in the food production. Traditional fermented foods are often the result of spontaneous fermentation, which produces a variety of microbial consortia that can be sources of useful microorganisms [8,9].

Fermentation is a low-cost preservation approach that enhances food safety and digestibility in many rural Malaysian and Indonesian homes. Most of the time, fermented foods come from homemade preparation, and usually involves cheap and locally accessible materials. These raw ingredients are easy to obtain and abundance in number, due to the tropical weather in Southeast Asia. Foods that have undergone biochemical modification during fermentation produce antimicrobial metabolites, boost vitamin B content, and eliminate antinutritional compounds [10]. *Tempoyak* fermentation, for example, improves durian pulp digestibility via LAB-mediated acidification [4], whereas *budu* fermentation produces amino acids and peptides that bring about its *umami* flavor [5].

Microbial Ecology of Fermented Foods in Southeast Asia

The microbial ecology of Southeast Asian fermented foods is dominated by LAB, yeasts, and *Bacillus* spp., which usually interact and cooperate with one another during fermentation. The predominant bacteria found in acidic and plant-based fermented foods such as *tempoyak* and *tapai* include *Lactiplantibacillus plantarum, Weissella confusa, Leuconostoc mesenteroides,* and *Pediococcus pentosaceus* [1,7]. *Bacillus subtilis, B. licheniformis*, and *B. amyloliquefaciens* drive the alkaline fermentations seen in *budu* and *belacan* [12]. Yeasts, particularly *Saccharomyces cerevisiae* and *Candida* spp., aid in the yield of flavor compounds and ethanol in *tapai* and *pekasam* [11]. This consortium-driven metabolism generates acidification, proteolysis, flavor enhancement, and bioactive metabolite synthesis, laying the groundwork for probiotic and postbiotic potential.

Malaysian Fermented Foods

Malaysia's traditional fermented dishes represent a unique fusion of multicultural culinary traditions. For example, the Malay community is known for fish- and vegetable-based fermented foods such as *budu*, *pekasam*, and *tempoyak*, while Chinese and Indian communities have introduced soy-based and dairy fermentations with different microbial compositions and flavor profiles. Indigenous groups, particularly those in Sabah and Sarawak, continue to use regional ingredients like sago, bamboo shoots, and rice wine in their traditional fermentation processes, which frequently involve spontaneous fermentations. *Tempoyak* (fermented durian pulp) is made through spontaneous lactic acid fermentation by *L. plantarum, W. paramesenteroides*, and *L. fermentum*, which yields lactic acid and exopolysaccharides with probiotic potential [1].

Budu and *cincalok* are fish-based fermented foods that contain proteolytic *Bacillus* and halotolerant LAB. They also produce peptides with antioxidant and antihypertensive qualities [13]. *Tapai* (fermented glutinous rice or cassava) is produced through a combination of *S. cerevisiae* and LAB fermentation, resulting in alcohol, organic acids, and beneficial esters [15]. Even though some studies have suggested probiotic potential of these microbes [12,13,15,16], little is known about their metabolite and postbiotic composition.

Table 1. Common fermentation methods and substrates used in the fermented food production and key microorganisms involved in the processes.

Fermentation type	Key microorganisms	Common substrates	Example of foods	Primary metabolites	Source
Lactic acid fermentation	*Lactobacillus plantarum*, *Leuconostoc mesenteroides*, *Weissella confusa*	Vegetables, cereals, dairy, fruits	Kimchi, sauerkraut, *tapai*, *tempoyak*	Lactic acid, carbon dioxide, peptides	[7]
Alcoholic fermentation	*Saccharomyces cerevisiae*, *Candida tropicalis*	Fruits, cereals, roots	*Tapai ubi*, palm wine, beer	Ethanol, carbon dioxide, esters	[11]
Alkaline fermentation	*Bacillus subtilis*, *B. licheniformis*, *B. amyloliquefaciens*	Legumes, fish, shrimp	*Budu*, *belacan*, natto	Ammonia, peptides, amino acids	[12,13]
Acetic acid fermentation	*Acetobacter aceti*, *Gluconobacter oxydans*	Fruit juices, alcohol	Vinegar, kombucha	Acetic acid	[14]
Mixed fermentation	LAB and yeast symbiosis	Fruits, starches	*Tempoyak*, kefir, sourdough	Organic acids, vitamins, carbon dioxide	[1]

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3Probiotics in traditional fermented foods of Southeast Asia and Malaysia

Probiotic concept and relevance in traditional fermented foods

Probiotics are defined as "live microorganisms that, when administered in adequate amounts, confer health benefits on the host" [2]. Traditional fermented foods in Southeast Asia are naturally rich in LABs, *Bacillus* spp., and yeasts, many of which match functional probiotic criteria. These microbes tolerate gastrointestinal conditions, attach to the intestinal mucosa, and have antimicrobial and immunomodulatory properties [7].
Malaysia's traditional fermented foods offer a wide range of variations, from acidic fruit-based fermented foods (e.g., *tempoyak*) to alkaline fish sauces *(*e.g., *budu, belacan*). These fermented foods serve as a living microbial reservoir for isolating novel probiotic strains that are suited to tropical, acidic, and high-salinity conditions. Studies have reported antioxidant, antibacterial, anti-inflammatory, and cholesterol-lowering qualities attributed to these probiotics [1,13]. Therefore, they are ideal in advancing for next-generation functional food in Malaysia [16].

Probiotic microorganisms identified from Southeast Asian fermented foods

In Southeast Asian fermented foods, the most commonly isolated lactic acid bacteria (LAB) are *Lactiplantibacillus plantarum, Weissella confusa, Pediococcus pentosaceus,* and *Leuconostoc mesenteroides*. They produce lactic acid, accumulate organic acids, and reduce pH, which create unfavorable growth environments for spoilage microbes. This shows that the LAB species help to extend the food's shelf life and ensure food safety [17]. **Table 2** summarizes the probiotics found in selected Malaysian traditional fermented foods.

Functional mechanisms of probiotic strains

The LAB and *Bacillus* species that were isolated from Malaysian fermented foods exhibit a range of functional mechanisms with health-promoting capacity. Organic acids and bacteriocins produced by a number of LAB strains, including *L. plantarum* and *Pediococcus* spp., suppress foodborne pathogens such as *Shigella, Salmonella,* and *Escherichia coli* [10]. Furthermore, LAB associated with fruit and vegetable-based fermentations such as *tempoyak* and pickled *maman* have antioxidant properties, as demonstrated by their capability to regulate oxidative stress *in vitro*, and scavenge free radicals [1]. Certain *Lactobacillus* strains contribute to cholesterol reduction by expressing bile salt hydrolase (BSH) activity, which improves cholesterol metabolism [23].

Beyond metabolic effects, LAB derived from fermented food have been reported to regulate immunological responses by increasing cytokine production and mucosal immunity [16]. Similarly, *Bacillus* species improve digestibility in alkaline or high-protein fermented foods such as *budu* and *belacan* by hydrolyzing complicated proteins into easily absorbed peptides [10,24]. Despite the promising findings, majority of the research remain descriptive, with a focus on isolation rather than functional or genomic validation. Few Malaysian fermented foods have undergone *in vivo* probiotic efficacy or safety evaluation, and postbiotic characterization is mainly lacking. By discovering bioactive substances, microbial interactions, pathways specific to traditional fermented foods, and emerging omics technologies (e.g., metabolomics and metagenomics) can help close this gap [7,25].

Table 2. Ingredients used to make selected Malaysian traditional fermented foods and the common probiotic species in the food products.

Fermented food	Main ingredients	Predominant microbial species	Functional role	Source
Tempoyak	Durian pulp, salt	*L. plantarum*, *W. confusa*, *L. mesenteroides*	Lactic acid fermentation	[1,4]
Budu	Anchovies, salt, palm sugar	*B. subtilis*, *Pediococcus acidilactici*, *B. licheniformis*	Proteolysis; peptide bioactivity	[1,5,12,13]
Cincalok	Small shrimp, rice, salt	*Weissella koreensis, Tetragenococcus halophilus*	Salt-tolerant LAB; antimicrobial peptide production	[1,12]
Belacan	Shrimp, salt	*B. amyloliquefaciens*, *Staphylococcus epidermidis*	Protease production	[1,12,13]
Tapai ubi (fermented cassava)	Cassava, starter culture (yeast inoculum)	*S. cerevisiae*, *Lactobacillus fermentum*, *C. tropicalis*	Mixed fermentation; alcohol & organic acid production	[1,18]
Tapai pulut (fermented glutinous rice)	Glutinous rice, starter culture (*ragi*)	*S. cerevisiae*, *L. plantarum*, *P. pentosaceus*	Co-fermentation; growth of probiotic LAB	[1,18]
Pekasam	Fish, rice, salt	*Lactobacillus sakei*, *L. plantarum*, *L. mesenteroides*	Acid production; pathogen inhibition	[1,12,13]
Taucu	Soybeans, brine	*Aspergillus oryzae*, *B. subtilis*	Proteolytic activity; amino acid enrichment	[19]
Pickled m*aman*	Wild spider flower, salt, rice water	*L. plantarum*, *L. mesenteroides*, *Lactiplantibacillus pentosus*	LAB-dominant fermentation	[15,20]
Fermented bamboo shoots (fermented *rebung*)	Bamboo shoots, salt	*Lactobacillus brevis*, *L. plantarum*	Lactic acid formation	[21]
Tempeh	Soybeans, *tempeh* starter (*Rhizopus oligosporus)*	*Rhizopus* spp., *L. plantarum*	Mycofermentation; protease & probiotic LAB synergy	[22]
Nata de coco (coconut gel)	Coconut water, sugar, acetic acid	*Komagataeibacter xylinus*	Bacterial cellulose production; beneficial fiber; prebiotic synergy	[7]

Table 3. Identified postbiotics in Malaysian traditional fermented foods and their functional beneftis.

Fermented food	Key microorganisms	Major postbiotic components	Functional benefits	Source
Tempoyak	*L. plantarum*, *W. confusa*	Lactic acid, acetic acid, bioactive peptides, exopolysaccharides	Antioxidant, anti-inflammatory, cholesterol reduction	[1,4]
Budu	*B. subtilis*, *P. acidilactici*	Proteolytic peptides, γ-glutamyl peptides, amino acids	Antihypertensive; antioxidant; digestive improvement	[1,5,12,13]
Cincalok	*W. koreensis*, *T. halophilus*	Organic acids, bacteriocins, exopolysaccharides	Antimicrobial; supporting gut health	[1,12]
Belacan	*B. amyloliquefaciens*, *B. subtilis*	Bioactive peptides, proteases, amino acids	Antioxidant; aiding in enzymatic digestion	[1,12,13]
Tapai ubi (fermented cassava)	*S. cerevisiae*, *L. fermentum*	Ethanol, lactic acid, SCFAs, esters	Antioxidant; metabolic regulation	[1,18]
Tapai pulut (fermented glutinous rice)	*S. cerevisiae*, *L. plantarum*	Ethanol, peptides, aromatic esters	Modulation of gut microbiota; sensory enhancement	[1,18]
Pekasam	*L. sakei*, *L. plantarum*	SCFAs, peptides, ethanol	Antimicrobial; immune improvement	[1,12,13]
Taucu	*A. oryzae*, *T. halophilus*	Amino acids, peptides, glutamic acid derivatives	Antioxidative potential; *umami* enhancement	[19]
Pickled *maman*	*L. plantarum*, *L. mesenteroides*	Lactic acid, exopolysaccharides, phenolic metabolites	Antioxidant; prebiotic synergy	[15,20]
Fermented bamboo shoots (fermented *rebung*)	*L. brevis*, *L. citreum*	Organic acids, phenolic metabolites	Anti-inflammatory; gut balance	[21]
Tempeh	*R. oligosporus*, *L. plantarum*	Isoflavone aglycones, peptides	Antioxidant; cholesterol reduction	[22]
Nata de coco	*K. xylinus*	Bacterial cellulose, acetic acid	Prebiotic fiber; gut barrier support	[7]

Postbiotics in fermented foods of Southeast Asia and Malaysia

Definition of postbiotics

Postbiotics are non-viable microbial cells, components, or metabolic by-products that enhance the host's physiology. According to the International Scientific Association for Probiotics and Prebiotics (ISAPP, 2021), postbiotics are "a preparation of inanimate microorganisms and/or their components that confer a health benefit to the host." [3]. Because of metabolic activity of the probiotic microbes, components such as short-chain fatty acids (SCFAs), exopolysaccharides, bacteriocins, enzymes, peptidoglycans, and cell wall fragments are produced [26]. Given their stability, reproducibility, and safety, postbiotics are drawing more interest in functional food science. This makes postbiotics suitable for use in nutraceutical and therapeutic applications. Postbiotics, unlike probiotics, are non-living, thus reducing the risk of microbial translocation or contamination in immunocompromised people.

Postbiotic's mechanisms and health benefits

There are several mechanisms that enable postbiotics produced from fermented foods promote human health. Organic acids, particularly acetic and lactic acids, help in regulating the gut microbiota by decreasing intestinal pH. This highly acidic environment allows beneficial microbes to flourish in the gut, while suppressing growth of pathogenic species [7]. Furthermore, structural components including peptidoglycans and bacterial cell wall fragments exhibit anti-inflammatory and immunomodulatory properties by increasing cytokine production and improving immunoglobulin responses [26].

Peptides and phenolic compounds produced by LAB and *Bacillus* spp. exhibit antioxidant and antihypertensive properties, including the ability to scavenge free radicals and regulate blood pressure [7,24]. Exopolysaccharides and bacterial surface proteins improve intestinal barrier function by reinforcing the gut mucosal layers and protecting epithelial integrity. In addition, fermentation-derived SCFAs participate in overall metabolic homeostasis by regulating glucose, lipid, and bile acid metabolism [7,26,27].

Identified and potential postbiotics from Malaysian fermented foods

While many Malaysian fermented foods have been investigated for probiotic properties, few have been thoroughly examined for postbiotics. According to current research, LAB, yeast, and *Bacillus* strains generate various types of bioactive metabolites that play a role in the food's sensory and functional qualities. **Table 3** summarizes postbiotic compounds identified or potentially present in traditional Malaysian fermented foods based on recent findings.

Synergy between probiotics and postbiotics

Traditional fermented foods frequently include both living microorganisms and their metabolites, resulting in a synergistic "probiotic-postbiotic continuum." [25]. This symbiotic relationship does not only enhance nutrition, but also increases the food product's functional value. For example, *L. plantarum* in *tempoyak* not only survives fermentation but also produces EPS and lactic acid, both of which work postbiotically to support gut integrity [28]. Similarly, *B. subtilis* in *budu* secretes bioactive peptides during fermentation that remain long after microbial death, maintaining functionality in the final food product [29].

Postbiotic science's integration into Malaysian fermented food research is still in its early stages. Studies have shown the presence of bioactive peptides in *budu* and *belacan*, EPS in *tempoyak*, and organic acids in *tapai*, but few have characterized their structures or bioavailability. The systematic quantification and identification of postbiotics in traditional Malaysian fermented foods is currently limited, especially for lesser-known foods such as pickled *maman* and fermented *rebung*. This demonstrates a major research gap in linking microbial diversity to specific bioactive metabolite production.

Underexplored Malaysian fermented foods, challenges, and future directions

Underexplored traditional Malaysian fermented foods

Aside from the well-known *budu*, *tempoyak*, and *belacan*, Malaysia has a diverse range of ethnic and regional fermented dishes. Several underexplored fermented foods show promise for probiotic and postbiotic properties, however they are rarely discussed in the scientific literature.

Pickled *maman* (*Cleome gynandra*)
Pickled *maman* is a traditional dish often found in Negeri Sembilan and the East Coast of Malaysia. Pickled *maman* has shown antimicrobial activity against pathogenic microorganisms [30, 31]. Preliminary research has identified phenol and flavonoid synthesis in this dish, indicating possible antioxidant and gut-protective benefits [32]. However, detailed omics studies that identify the entire microbiome or postbiotic profile are still absent.

Fermented *rebung* (bamboo shoots)
Fermented *rebung*, which is commonly produced in rural communities, contains a wide range of LAB, including *Lactobacillus brevis* and *Leuconostoc citreum*. Despite its popularity, there is little published research identifying its probiotic species or discovering bioactive peptides and phenolics [9].

Fermented cassava leaves
Similar to other fermented vegetables, the presence of LAB strains in fermented cassava leaves indicates possible probiotic effects [33]. Nevertheless, no previous research has identified postbiotic metabolites nor characterized the probiotic functionality in these leaves.

Fermented *petai* beans
Petai (*Parkia speciosa*) beans have not been investigated as a fermented product. *Petai* seeds and pods contain bioactive compounds with antioxidant and antibacterial properties [34], however these are derived from raw plant extracts rather than fermentation. These phytochemicals may provide health benefits when consumed, but they do not represent postbiotic products of microbial fermentation.

Pickled garlics
Pickled garlic has been shown to contain LAB commonly associated with probiotic activity. *L. sakei* that is isolated from sweet pickled garlic exhibited antioxidative and potential antimicrobial effects *in vitro* [35]. Multiple *Lactobacillus* and *Pediococcus* spp. from traditional pickled garlic showed acid and bile tolerance, which is characteristic of probiotic candidates [36]. However, there is insufficient information on direct postbiotic profiling.

Pickled chillies
Pickled chillies have been shown to contain dominant LAB such as *Lactiplantibacillus* and *Weissella* [37]. Metabolomic profiling of pickled chillies has found fermentation-associated metabolites such as lactic acid and 3-phenyllactic acid that may operate as postbiotic compounds (38). The scarcity of data highlights the urgent need to explore the microbiome-metabolome correlation in these lesser-known fermented foods, which may uncover new species of probiotic bacteria with industrial potential.

Challenges in investigating probiotics and postbiotics in Malaysian fermented foods
Several challenges hamper the growth of postbiotic and probiotic research in Malaysian fermented foods. Insufficient financing is a major issue in scientific research. To obtain high-resolution identification of microbial metabolites, omics tools are useful. However, comprehensive multi-omics investigations (e.g., metagenomics, metabolomics) can be expensive, depending on the project scale [39]. The handling and preparation of fermented foods lacks standardization. Due to the many variations in traditional preparation methods, reproducibility and microbial consistency can be greatly affected. Aside from that, safety assessments have been scarce, with only a few studies evaluating potential biogenic amine accumulation, antibiotic resistance genes, or isolate cytotoxicity [40,41]. Postbiotic characterization can be challenging to carry out because of the complex combination of multiple components [41]. Lastly, there is a lack of collaboration between academia and industry. It is difficult to convert lab results into functional foods that are sold commercially due to gaps in technological transfer.

Future directions
In future studies on fermented foods in Southeast Asia and Malaysia, integration of omics technology should be useful in mapping microbial-metabolite interactions in greater depth, but this approach should be supported with more research funds [39]. By using native microbial strains (such as *L. plantarum* from *tempoyak*) as starter cultures, production of fermented foods can be standardized while maintaining local authenticity [1]. Development of standardized starter cultures derived from local LAB strains could also help to guarantee reproducibility and food safety. Research on the stability of postbiotic formulations will open the door for commercial use in functional foods.

CONCLUSION

Fermented foods from Southeast Asia, particularly those from Malaysia, offer a vast range of beneficial microorganisms and biochemical substances that improve their functional potential for human health. Studies have identified probiotics derived from LAB and *Bacillus* spp., and the associated postbiotics (i.e., exopolysaccharides, SCFAs, peptides, and phenolic compounds). These discoveries reveal new possibilites for health and industrial applications. Despite growing interest, challenges remain in standardizing fermentation processes, characterizing microbial metabolites, and assuring safety of food product. For further studies on these traditional fermented foods, researchers should focus on developing standardized starting cultures from local probiotic strains, assess clinical efficacy, and utilize omics techniques for comprehensive microbial-metabolite mapping. To transform Malaysian traditional fermented foods into nutraceutical products, more collaborative efforts should be fostered among academia, industry, and local communities. Additionally, policy and regulatory frameworks to define probiotic and postbiotic labeling standards in Malaysia and ASEAN should be established. With the leverage of Malaysia's rich biodiversity and culinary heritage, these research initiatives have potential to make Malaysia a regional leader in functional fermentation science.

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CONFLICT OF INTEREST

No conflict of interest.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES

While preparing this manuscript, we utilized AI-based tools such as ChatGPT, Consensus, and Quillbot to assist in tasks related to data collection, analysis, and manuscript editing. These tools were employed as supplementary aids and did not contribute to the interpretation of data or the drawing of scientific conclusions. The final interpretation, conclusions, and overall scholarly content, including the articulation of arguments, are the authors' sole responsibility. The authors have reviewed and edited the content after using these tools and assume full responsibility for the integrity and accuracy of the published work.

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