International Journal of Agriculture, Environment and Biotechnology
Citation: *IJAEB*: **17**(04): 765-773, December 2024
DOI: 10.30954/0974-1712.04.2024.15

ASSOCIATION FOR AGRICULTURE ENVIRONMENT AND BIOTECHNOLOGY

REVIEW PAPER

Biocontrol Potentials of *Bacillus* Species: A Focus on the Emerging *Bacillus nakamurai*

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Paper No. 1195 **Received:** 08-09-2024 **Revised:** 23-11-2024 **Accepted:** 01-12-2024

ABSTRACT

The genus *Bacillus* includes a diverse range of Gram-positive, spore-forming bacteria, recognized for their ability to produce a variety of bioactive compounds with antimicrobial properties. There are many studies indicating the application of these compounds as alternatives in sustainable agriculture practices. The scientific and medical community face an alarming threat on account of the increase in antimicrobial resistance among bacteria and fungi. Natural antimicrobial peptides from *Bacillus* species can be a promising alternative for antibiotics and hence a potential treatment for infectious diseases caused by multidrug-resistant microorganisms. This review highlights research on the potential of Bacillus species as viable sources of environmentally friendly biocontrol agents. The newly identified member in the genus, *Bacillus nakamurai*, is a soil saprophyte. Recent research has revealed its ability to produce a diverse range of secondary metabolites, including non-ribosomal peptides like surfactin and bacillaene, as well as ribosomally synthesized peptides such as plantazolicin. These metabolites exhibit strong activity against various bacterial and fungal pathogens, positioning *B. nakamurai* as a promising biocontrol agent for agriculture. A comparative genomic analysis of five sequenced *B. nakamurai* strains revealed that non-ribosomal products dominate the species' core metabolome, while ribosomally synthesized and post-translationally modified peptides (RiPPs) are more unique to individual strains. This review proposes the need for exploring the antimicrobial capabilities of *B. nakamurai* and enhances its role in biocontrol strategies for both clinical and agricultural applications.

HIGHLIGHTS

- The genus *Bacillus* produces diverse bioactive compounds with antimicrobial properties, offering sustainable solutions in agriculture.
- Antimicrobial peptides from *Bacillus* species serve as promising alternatives to combat multidrug-resistant pathogens.
- Bacillus *nakamurai*, a newly identified soil saprophyte, synthesizes non-ribosomal peptides like surfactin and bacillaene, along with ribosomally synthesized peptides such as plantazolicin.
- Comparative genomic analysis of *B. nakamurai* strains reveals the dominance of non-ribosomal peptides in the core metabolome and unique ribosomally synthesized peptides (RiPPs) among strains.
- *B. nakamurai* shows potential as an effective biocontrol agent, emphasizing its relevance in clinical and agricultural applications.
- The study underscores the need for further research on *B. nakamurai*'s antimicrobial capabilities and its role in sustainable biocontrol strategies.

Keywords: *Bacillus* sp., *Bacillus nakamurai*, Biocontrol potentials, Novel metabolites, Antimicrobial peptides, Clinical applications

How to cite this article: Mehara, N., Jacob, A.A., Pillai, A.R. and John, A. (2024). Biocontrol Potentials of *Bacillus* Species: A Focus on the Emerging *Bacillus nakamurai*. *Int. J. Ag. Env. Biotech.*, **17**(04): 765-773.

Source of Support: None; **Conflict of Interest:** None

The genus *Bacillus* includes a diverse range of Gram-positive, spore-forming bacteria that can be found in various habitats, such as soil, water, and the surfaces of plants (Checinska *et al.* 2015). These microorganisms are characterized by their metabolic versatility, allowing them to adapt to different environmental conditions. Additionally, they possess the capability to produce an array of bioactive compounds, which includes antibiotics, lipopeptides, and enzymes. This remarkable biochemical production not only enhances their survival in challenging environments but also contributes to their significance in agriculture and biotechnology. The ability to generate such a wide range of bioactive substances makes *Bacillus* species valuable for various applications, including pest control and the promotion of plant growth (Dame *et al.* 2021).

Many *Bacillus* species are distinguished by their ability to produce antimicrobial compounds, which give them a competitive edge in their natural habitats and make them promising for various practical applications. A key feature of *Bacillus* species is their mature endospores, which demonstrate exceptional resilience. These endospores are capable of surviving harsh conditions such as intense heat, ultraviolet (UV) and gamma radiation, dehydration, and exposure to toxic chemicals, including concentrations of up to 5% hydrogen peroxide and hydrolytic enzymes like lysozyme. For example, endospores of *Bacillus subtilis* (Marburg strain) survived six years of exposure to solar radiation in space, with up to 10^4 spores remaining viable in multilayer samples, and even higher survival rates when protected with a phosphate buffer and 5% glucose (Checinska *et al.* 2015; Dame *et al.* 2021).

Secondary metabolites produced by *Bacillus* species have become a focal point for natural product chemistry research. The extensive structural diversity of these compounds has intrigued chemists and inspired the pharmaceutical industry to investigate microbial extracts for potential drug candidates. The analysis of microbial extracts reveals an extensive range of natural compounds with diverse structures and biological activities, such as antimicrobial, antiviral, immunosuppressive, and antitumor properties. These compounds play a crucial role in helping bacteria survive and thrive in their natural environments (Sansinenea and Ortiz 2011).

Given their remarkable adaptability, resilience, and capacity to produce a wide range of bioactive compounds, *Bacillus* species not only contribute to soil health and plant growth but also represent a rich source of antimicrobial agents with potential applications in agriculture and medicine. Among these species, *Bacillus nakamurai* has emerged as a particularly promising candidate for biocontrol, warranting further investigation into its antimicrobial properties and practical applications.

Biocontrol Potentials of *Bacillus* Species in Agriculture

The increasing demand for sustainable agricultural practices has driven research toward the development of eco-friendly alternatives to chemical pesticides and synthetic fertilizers.

Among the promising solutions, plant growth-promoting rhizobacteria (PGPR) such as *B. subtilis* have garnered attention for their ability to enhance crop productivity and control of plant pathogens. In agriculture, *Bacillus* species are recognized as effective biocontrol agents capable of suppressing plant pathogens. *Bacillus* species have been recognized for their roles as plant growth promoters, inducers of systemic resistance, and producers of a wide range of bioactive compounds such as lipopeptides, antibiotics, and enzymes. They compete with pathogenic microorganisms for resources like space and nutrients through colonization. Various *Bacillus* species secrete bioactive peptides namely fengycin, iturin, surfactin and bacillomycin, which exhibit antifungal, antibacterial, and surfactant properties. The use of *Bacillus* species promotes more sustainable crop management practices by reducing the dependence on chemical pesticides. In a study conducted by Jan *et al.* (2023), the potential of *B. subtilis* strain FJ3 for biocontrol and plant growth promotion was evaluated, highlighting its multifaceted role in sustainable agriculture. A different study investigated the effect of different plant pathogens on lipopeptide production by *B. subtilis* strain, PTB185. The results demonstrated that both the antagonistic activity and lipopeptide synthesis varied significantly depending on the specific pathogen present. Notably, the inclusion of autoclaved mycelia from pathogens like *Botrytis* *cinerea*, *Mucor* sp., *Pythium ultimum*, and *Rhizoctonia solani* led to increased production of fengycin and iturin, whereas surfactin levels remained unchanged. Additionally, *B. subtilis* cultured with *Mucor* sp. mycelium showed enhanced inhibition of mycelial growth in *B. cinerea*, *R. solani*, and *Sclerotinia sclerotiorum* (Jan *et al.* 2023; Bouchard-Rochette *et al.* 2022).

The study conducted by O.A. Mohamad *et al.* (2018), on antimicrobial potential of endophytic bacteria isolated from *Glycyrrhiza uralensis* (licorice), was focused on strains of *Bacillus atrophaeus* and *Bacillus mojavensis*. These bacteria exhibited broad-spectrum antifungal and antibacterial activity, and showed potential for biocontrol against plant pathogens such as *Verticillium dahliae* in *Arabidopsis thaliana*. Key secondary metabolites were identified from these bacteria, suggesting their role in plant resistance to diseases and making them promising candidates for sustainable agriculture applications (Mohamad *et al.* 2018).

Another study highlights the antimicrobial potential of various *Bacillus* species, including *B. subtilis*, by Todorova and Kozhuharova (2010), *B. subtilis* strains isolated from soil were evaluated for their potential use as natural biological control agents. The strains demonstrated significant antagonistic activity against several phytopathogenic fungi. Similarly, Wise *et al.* (2012), investigated *B. subtilis* strain CU12 for its antimicrobial activity against several phytopathogenic fungi, revealing significant inhibition of mycelial growth. Their findings showed that the antimicrobial activity of *B. subtilis* CU12 is partly due to 3-hydroxypropionaldehyde [HPA] production, suggesting its effectiveness in controlling pathogens through antibiosis and protecting its ecological niche. In a study by Jeong *et al.* (2017), *Bacillus licheniformis* MH48 was isolated from rhizosphere soil and shown to have strong antifungal properties against several plant pathogens, including *Rhizoctonia solani*, *Colletotrichum gloeosporioides*, and *Phytophthora capsici*. The researchers demonstrated that 50% concentration of the bacterial cell-free culture filtrate from *B. licheniformis* MH48 was highly effective against these fungi. These findings suggest that *B. licheniformis* MH48, through the production of benzoic acid, could serve as a promising biological control agent for managing various fungal pathogens in plants (Todorova and Kozhuharova, 2010; Wise *et al.* 2012; Jeong *et al.* 2017). A study by Jebur and Auda (2020), concentrated on the production and assessment of the antimicrobial properties of bacteriocin extracted from *Bacillus licheniformis*, which was isolated from soil samples in corn and sunflower fields (Jebur and Auda, 2020).

Fusarium species are known for causing diseases in a wide range of crops, leading to substantial agricultural losses and posing a risk to food security. The biocontrol efficiency of rhizospheric *Bacillus* against *Fusarium oxysporum*, was demonstrated by S. Boulahouat *et al.* (2023), showcasing its promise for sustainable agricultural practices (Boulahouat *et al.* 2023). Moreover, *Bacillus subtilis* and *Bacillus tequilensis* has the ability to inhibit the growth of key *Fusarium* species— *Fusarium oxysporum*, *Fusarium proliferatum*, *Fusarium culmorum*, and *Fusarium verticillioides* (Baard *et al.* 2023). In a similar study by Lee *et al.* (2017), *Bacillus amyloliquefaciens* strain DA12 was isolated from soil and evaluated for its potential as a biological control agent against mycotoxigenic *Fusarium* species. The strain demonstrated significant antimicrobial activity both in vitro and in plants (maize) against several *Fusarium* species, including *F. asiaticum*, *F. proliferatum*, *F. graminearum* and *F. verticillioides*. Further testing revealed that DA12 also inhibited other fungal pathogens such as *Botrytis cinerea*, *Endothia parasitica*, *Colletotrichum coccodes*, *Fusarium oxysporum*, *Raffaelea quercus-mongolicae*, and *Rhizoctonia solani*. Antagonistic activity of *B. amyloliquefaciens* DA12 is largely due to the combined effects of iturin A and volatile heptanones, positioning the strain as a promising candidate for reducing *Fusarium* diseases and mycotoxin contamination in crops (Lee *et al.* 2017).

Bacillus velezensis isolates are a rich source of secondary metabolites, with many biosynthetic gene clusters identified in recent years through whole-genome sequencing. These gene clusters encode enzymes responsible for the production of diverse antimicrobial compounds. The antimicrobial activities of polyketides and lipopeptides produced by *B. velezensis* have been explored for agricultural applications, emphasizing the importance of these compounds in enhancing plant health (Fazle Rabbee and Baek, 2020). A novel bacterial strain isolated from soil demonstrated broad-spectrum and potent antifungal activity. The strain was identified using biochemical and molecular methods, with 16S rRNA gene sequencing showing over 98% similarity to *B. amyloliquefaciens* ATCC 23350T and *B. velezensis* BCRC 17467T. However, the isolated strain exhibited distinct biochemical characteristics, including a unique cellular fatty acid composition with anteiso-C15:0 as the predominant fatty acid (Hajare *et al.* 2016). In a similar study, conducted by Torres *et al.* (2020), *B. velezensis* XT1, a halotolerant bacterium which was isolated from a habitat in Spain that was saline in nature, was evaluated for its plant growth promotion and antifungal activity. The researchers found that with direct application to soil, strain XT1 significantly enhanced the aerial fresh weight of horticultural crops, including tomato, pepper, pumpkin, and cucumber, by 53%, 63.6%, 129.2%, and 100.8%, respectively. Tomato plants exhibited the most substantial improvements in height, number of flowers, and fruit count. Strain XT1 exhibits various metabolic characteristics, including the ability to fix nitrogen, solubilize both organic and inorganic phosphate, produce siderophores and synthesize enzymes like urease and 1-aminocyclopropane-1-carboxylate deaminase (Torres *et al.* 2020).

B. amyloliquefaciens FZB42 was investigated for its biocontrol potential against bacterial blight and bacterial leaf streak in rice, diseases caused by *Xanthomonas oryzae* pv. *oryzae* and *X. oryzae* pv. *oryzicola*. The researchers found that *B. amyloliquefaciens* FZB42 exhibited significant biocontrol activity through the production of antibiotic compounds, specifically bacilysin and difficidin (Wu *et al.* 2015).

In addition to these metabolites, plantazolicin, a molecule containing thiazole and oxazole rings, was identified in *B. amyloliquefaciens* for its antibacterial activity against certain Grampositive bacteria. Plantazolicin also demonstrates nematicidal properties against *Caenorhabditis elegans* (Liu *et al.* 2013).

The use of *Bacillus* species for biocontrol offers a sustainable alternative to chemical pesticides by promoting plant growth, inducing systemic resistance, and competing with pathogenic microorganisms for resources. Their role in reducing the environmental impact of conventional agriculture, positions *Bacillus* as an essential tool for future crop management practices (Zhang, *et al.* 2023).

Antimicrobial properties of *Bacillus* Species against medically important pathogens

Bacillus species have been shown to exhibit broad-spectrum antimicrobial activity against various pathogenic microorganisms. The antimicrobial peptides (AMPs) produced by *Bacillus* can be synthesized either ribosomally or non-ribosomally and are categorized based on their biosynthesis mechanisms, structural characteristics, and molecular weight. They produce a diverse array of secondary metabolites which have distinct mechanisms of action, ranging from disrupting cell membranes to inhibiting essential metabolic pathways in pathogenic microorganisms (Sumi *et al.* 2015; Caulier *et al.* 2019; Muras *et al.* 2021).

In a recent study *B. velezensis* strain, BVM7 isolated from the mouse gut displayed robust growth-inhibitory activity against the human enteric *Vibrio cholera* and several other opportunistic bacteria (Byun *et al.* 2023). Similarly, *B. subtilis* BSP1 has appeared to be a promising candidate for antibiotic production, with significant antimicrobial and antioxidant properties and a favorable safety profile (Hellany *et al.* 2024).

In recent years, biosurfactants have gained attention for medical applications, particularly in combating various diseases. The crude extracts of surfactin (lipopeptide surfactant) and rhamnolipid (glycolipid surfactant) produced by *B. amyloliquefaciens* exhibited strong antimicrobial activity against a wide range of opportunistic and pathogenic microorganisms, including antibiotic-resistant strains of *Staphylococcus aureus* and *Escherichia coli*, as well as the pathogenic yeast *Candida albicans* (Ndlovu *et al.* 2017). Ghribi *et al.* (2012) explored the production of biosurfactants by *B. subtilis* SPB1, noting their antimicrobial activity against various bacteria and fungi, particularly against multidrug-resistant organisms including *S. aureus*, *Staphylococcus xylosus*, *Enterococcus faecalis*, *Klebsiella pneumonia* (Ghribi *et al.* 2012). In-addition, octapeptins, a class of lipopeptide antibiotics initially isolated from *Bacillus circulans*, predominantly target Gram-negative bacteria with some activity against Gram-positive bacteria and fungi (Velkov *et al.* 2018).

The culture supernatants of *B. amyloliquefaciens* EMD17, isolated from Cheonggukjang, inhibited the growth of *Bacillus cereus* ATCC14579, *Listeria monocytogenes* ATCC19111, and an ochratoxin-producing *Penicillium* species. The antimicrobial activity was found to be resistant to heat, pH fluctuations, and protease treatments, indicating that the active antimicrobial substance is non-proteinaceous. This study conducted by Lee J.Y. *et al.* (2016), detected the presence of the *srf*AA gene, coding for surfactin synthetase A, through PCR analysis, and suggested surfactin as the likely key antimicrobial agent (Lee *et al.* 2016).

Another study explored the antifungal and bactericidal properties of *B. amyloliquefaciens* strain ELI149. The researchers isolated two heat stable bacteriocin-like substances (BLSs) with broad-spectrum antimicrobial activity and antifungal compounds; surfactin and fengycin. The research concluded that while the two isolated BLSs demonstrated notable bactericidal properties, fengycin was primarily responsible for the antifungal activity (Salazar *et al.* 2017). Gharieb, Rizk, and Elfeky, (2024) evaluated the ability of *B. subtilis* to inhibit the growth of clinical isolates of *C. albicans* (a pathogenic yeast responsible for candidiasis) (Gharieb *et al.* 2024).

The emergence of multi-drug-resistance in microbes poses a significant threat to public health, necessitating the urgent discovery of new antimicrobial agents. Bacteria of the genus *Bacillus* are recognized for their potential to inhibit various pathogens, making them promising candidates in the search for new antimicrobial agents.

Antimicrobial Activity of *Bacillus* Species against *Staphylococcus aureus*

Biofilms

Staphylococcal wound infections can range from mild to severe, with the potential for lifethreatening complications. A key challenge in managing these infections is bacterial biofilm formation, which significantly contributes to failure of antibiotic treatments and the recurrence of infections. Many researches have highlighted the potential of metabolites from *Bacillus sp* as effective against resistant *S. aureus*, indicating their relevance in developing new strategies for combating bacterial infections (Sabino *et al.* 2023; Chalasani *et al.* 2015).

A recent study investigated the potential of sponge associated *Bacillus pumilus* to combat multi drug resistant [MDR] *S. aureus*. The study specifically demonstrated effective bactericidal activity of the compound Bp1-AdE from *B. pumilus* 64-1, at a concentration of 1.550 µg/ml against both *S. aureus* ATCC29213 and MRSA strains (Freitas-Silva *et al.* 2024).

S. Ray *et al.* (2023) demonstrated the cell free supernatant of *B. thuringiensis* to be effective against *S. aureus* biofilms. Their results threw light on the potential of natural molecules produced by *the organism* to inhibit biofilm formation by *S. aureus* (Ray *et al.* 2023).

A recent study explored soil-derived bacteriocin-producing *B. cereus* strains, and their potential to inhibit methicillin-resistant *S. aureus* (MRSA) biofilms (Dhanam *et al.* 2021).

In the study conducted by Algburi *et al.* (2021), the antimicrobial effects of *B. subtilis* KATMIRA1933 and *B. amyloliquefaciens* B-1895 were tested against biofilms of *S. aureus* which were isolated from infections arising from wounds. The study focused on four clinical isolates, including two methicillin-resistant *S. aureus* and two methicillin-sensitive *S. aureus* (MSSA). The findings indicated that combining cefotaxime with the cell-free supernatants of *B. subtilis* KATMIRA1933 and *B. amyloliquefaciens* B-1895 exhibited complementary antimicrobial activity against the staphylococcal isolates. Furthermore, the co-aggregation potential of these beneficial bacteria with the *Staphylococcus* isolates was assessed, showing high co-aggregation scores (Algburi *et al.* 2021).

Bacillus paralicheniformis NNS4-3, a strain sourced from mangrove sediment has been discovered to produce a novel bacitracin-like antimicrobial peptide (AMP) that demonstrates strong activity against methicillin-resistant *S. aureus* (MRSA). This AMP shows significant potential in combating MRSA, highlighting the promise of *B. paralicheniformis* as a source of innovative antimicrobial compounds in the on-going battle against resistant pathogens (Sermkaew *et al.* 2024).

Taxonomy and Biological Characteristics of *Bacillus nakamurai*

Bacillus nakamurai sp. nov. is a newly discovered bacterial species distinguished by its unique ability to produce black pigment. This strain was isolated during an extensive study exploring the diversity of the *Bacillus* genus in soil samples, aimed at uncovering novel species with distinct properties. Upon isolation, detailed morphological and physiological analyses revealed that *B. nakamurai* possesses several key traits that set it apart from closely related species within the *Bacillus* genus. These distinguishing characteristics include its pigmentation, growth patterns, and physiological behaviours, which suggest its potential as a unique addition to the expanding classification of *Bacillus* species.

Morphologically, *B. nakamurai* is classified as a Gram-positive, strictly aerobic bacterium. The cells are motile and rod-shaped, and they possess the ability to form endospores, a characteristic feature of the *Bacillus* genus. When cultured on trypticase soy agar (TGY), the colonies exhibit a creamy white, mucoid, translucent, raised appearance, and typically measure 3–4 mm in diameter after 48 hours of incubation at 37 °C on Reasoner's 2A (R2A) agar. This strain exhibits the ability to grow on various media types, such as Nutrient Agar (NA), Luria-Bertani (LB) agar, R2A agar, Tryptic Soy Agar (TSA), and TGY agar. A distinguishing feature is the production of a black pigment when cultured on peptone iron agar after 72 hours at 30°C. *B. nakamurai* can grow across a wide range of environmental conditions, with growth occurring at pH levels from 5.5 to 10 and temperatures between 17°C and 50°C. Its optimal growth occurs at 37°C at a neutral pH of 7.0. Additionally, it can withstand sodium chloride concentrations up to 9% (w/v).

Biochemical tests show that *B. nakamurai* is catalase-positive and oxidase-negative, aiding in its identification. Its cell wall contains meso-diaminopimelic acid, a common peptidoglycan component in certain *Bacillus* species, and fatty acid profiling reveals key fatty acids, including anteiso-C15:0, iso-C15:0, iso-C17:0, anteiso-C17:0, and C16:0. Metabolically, *B. nakamurai* can utilize citrate and is capable of hydrolysing starch, gelatin, and casein, which reflects its ability to break down complex organic substances. It produces acid from glucose without generating gas, a property that can be useful for further characterization and classification of the strain.

Phylogenetic analysis conducted using 16S rRNA gene sequences, places *B. nakamurai* in close relation to *B. subtilis* subsp. *inaquosorum* and *Bacillus axarquiensis*, with a remarkable similarity of 99.7%. Despite this close relationship, *B. nakamurai* forms a distinct clade, indicating its unique position within the *Bacillus* phylogeny. The bioactive compounds produced by *B. nakamurai* offer significant potential for applications in healthcare, agriculture, and food preservation. With their ability to inhibit pathogenic microorganisms, these metabolites could be explored as novel therapeutic agents or as natural preservatives in food systems. Additionally, the use of *B. nakamurai* in sustainable agricultural practices could enhance crop resilience against pests and diseases (Dunlap *et al.* 2016; Ngalimat *et al.* 2021).

Emerging Research on *Bacillus nakamurai*

Recent research has increasingly focused on discovering new species within the *Bacillus* genus, such as *B. nakamurai*, which exhibit promising antimicrobial activities. This newly described species is being investigated for its potential to combat a wide range of microbial pathogens, underscoring its role as crucial contributors to biological control in agricultural systems and as potential sources of novel antibiotics for clinical use.

In a study, on halo-tolerant plant growth-promoting rhizobacterium (PGPR) strains, *B. nakamurai* MSRH1 was identified as an effective PGPR for wheat under saline soil conditions. The strain showed key growth promoting capabilities, primarily through phosphate solubilization, which is crucial for enhancing nutrient availability in challenging soil conditions. Additionally, *B. nakamurai* MSRH1 produced indole acetic acid (IAA) and exopolysaccharides (EPS) under saline stress , both of which play significant roles in promoting root growth, stress tolerance and maintaining plant-water balance. When applied as encapsulated beads, *B. nakamurai* MSRH1 demonstrated improved colonization on wheat roots, as confirmed by electron microscopy. Field trials showed that inoculation with this encapsulated form led to increased relative water content in plants, a reduction in proline accumulation and decreased electrolyte leakage (Saberi Riseh *et al.* 2021).

In a recent research study by Nimbesheho *et al.* (2024), investigated the biocontrol potential of the newly identified *B. nakamurai* strain, BDI-IS1 isolated from tropical soils in Burundi. They investigated the ability of the strain to inhibit various bacterial and fungal phytopathogens through a combination of genomic analysis, invitro assays and greenhouse experiments. The authors found that BDI-IS1 produces various secondary metabolites including surfactin, iturin A, bacillaene , bacilysin and bacillibactin and ribosomally synthesized peptides such as plantazolicin, Linear Cationic Antimicrobial peptide (LCI) and bacinapeptin. The compounds exert antimicrobial effects against bacterial and fungal pathogens. The authors showed reduction in foliar diseases caused by *Alternaria solani* and *Exserohilum turcicum* and induction of plant defense mechanisms. The antimicrobial property of the strain was found to be similar to *B. velezensis* QST713, a prominent biocontrol agent in agriculture (Nimbesheho *et al.* 2024).

S.Y. Wang *et al.* (2022), reviewed the antifungal role of *B. amyloliquefaciens* group members, constituting *B. amyloliquefaciens* , *B. velezensis*, *B. siamensis* and *B. nakamurai*. They reported antifungal properties of *B. nakamurai* through multiple mechanisms such as production of lipopeptides, volatile organic compounds and inducing disease resistance in host plants (Wang *et al.* 2022).

Leathers *et al.* (2020) investigated various potential inhibitors for suppressing *Erwinia amylovora*, the bacterium responsible for fire blight (a devastating disease affecting pear and apple). The culture supernatants from *B. nakamurai* demonstrated inhibitory effects on *E. amylovora* with the minimal inhibitory concentration ranging between 5-20% (vol/vol) against all tested strains of *E. amylovora*, marking it as a promising source of novel antimicrobial agents against this significant fruit crop pathogen (Leathers *et al.* 2020). The evidences on production of various metabolites with antimicrobial property by *B. nakamurai* steers towards exploring its biocontrol properties towards medical applications.

CONCLUSION

This review highlights the antimicrobial potentials of *B. nakamurai*, a recently identified species within the *Bacillus* genus. The ability of *B. nakamurai* to produce a diverse range of bioactive compounds, including non-ribosomal peptides and ribosomally synthesized peptides, positions it as a promising biocontrol agent in agriculture. Its effectiveness against a variety of bacterial and fungal pathogens demonstrates its potential for reducing foliar diseases in plants through direct antibiosis and by stimulating plant defense mechanisms. As agricultural practices increasingly shift toward sustainable methods, *B. nakamurai* could play a crucial role in developing environmentally friendly strategies for pest and disease management.

While many *Bacillus* species have been explored clinically based on their probiotic properties and their bacteriocin production, *B. nakamurai* has yet to be thoroughly investigated in this context. This review builds on recent studies documenting the inhibitory activity of *B. nakamurai* against phytopathogens and proposes further exploration of its clinical potential. Future research is warranted to fully explore its mechanisms of action and optimize its use, paving the way for innovative solutions in both fields.

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