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Effect of Core Root-Zone Microorganisms on Mango Growth Across Different Regions

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Abstract. This study aimed to explain how key root-zone microorganisms affect mango growth and fruit quality in different regions. It provided theoretical support for targeted regional microbial control in mango cultivation. We chose three main mango-growing areas: Hainan, Yunnan and Southeast Asia. We used field test data from local mango orchards and high-throughput sequencing technology to analyze root-zone microbial community features. These features are shaped by soil and climate factors such as pH, altitude and humidity. The results showed a clear "core-stable + region-specific" distribution pattern in mango root-zone microbes. Stable core microbes meet mangoes' basic growth and metabolic needs, while area-specific microbes help the crop adapt better to local environmental stresses. Using too many chemical fertilizers and pesticides, together with extreme weather, breaks the balance of microbial communities. It causes soil quality to drop, reduces helpful microbial types, and then lowers mango yield and fruit quality. Targeted microbial control methods are effective. These methods include using custom microbial inoculants, breeding weather-resistant microbial strains and using integrated disease control. They restore soil microbial balance, improve soil health, and greatly increase mango yield, fruit quality and environmental stress resistance. This builds a solid scientific base for sustainable and region-specific mango growing.

Keywords: Core Root-Zone Microorganisms, Regional Differences, Influence, Soil Properties, Microbial Management

1. Introduction

Mango (Mangifera indica L.) shows great differences in yield and fruit quality across growing areas. The fruit quality includes sweetness, color, size, aroma and soluble solids content. People used to believe these differences are caused by non-living factors. One factor is soil texture. For example, loamy soils with good water retention and air penetration help plants take in nutrients evenly, while sandy soils usually make nutrients get washed away [1]. The other factor is climate, such as temperature, rainfall and light intensity. These factors control important plant processes like photosynthesis, flowering and fruit ripening [1]. But more and more studies show that soil microbes around plant roots also play a very important role in mango growth and fruit quality. These microbes form a complex group near roots, and people did not notice their importance before. For example,

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Bhattacharyya and Jha [2] found that plant growth-promoting rhizobacteria (PGPR), such as Bacillus subtilis and Pseudomonas fluorescens, can break down phosphate.

Microbes around roots are a key part of soil microbes. They include many different groups, such as bacteria, fungi, archaea and protozoa. Bacteria and fungi are the most functional ones [2]. At the phylum level, common bacterial groups are Proteobacteria (such as Pseudomonas, Bacillus and Rhizobium), Actinobacteria (such as Streptomyces) [2], Firmicutes and Bacteroidetes. These bacteria exist in all farmlands. They help recycle nutrients, stop harmful germs and promote plant growth. For example, in wheat root areas, Pseudomonas spp. (Proteobacteria) break down inorganic phosphate to make phosphorus easier to absorb. Meanwhile, Rhizobium (Proteobacteria) grows with bean plants like soybeans to take in nitrogen from the air [3]. The main fungi in root areas include Ascomycota (such as Trichoderma), Basidiomycota (such as ectomycorrhizal fungi) and Glomeromycota (such as arbuscular mycorrhizal fungi, AMF, Rhizophagus). In tomato root areas, AMF (Glomeromycota) stretch the root system to take in more water and nutrients, especially phosphorus. Trichoderma (Ascomycota) fights against harmful soil germs like Fusarium oxysporum, so plants get sick less often.

The composition and number of these root microbes are quite different in different regions. This is caused by different soil properties (such as pH, organic matter content and nutrient level) and climate conditions (such as temperature, rainfall and altitude) [4]. For example, acidic soils (pH < 5.5) are common in tropical areas like Hainan, China. Fungi grow better in these soils because they can stand lower pH than most bacteria. In contrast, neutral to alkaline soils (pH 7.0–8.5) in dry areas have more kinds of bacteria. Actinobacteria grow well in dry and airy soils [5]. High-altitude areas like Yunnan, China have low temperatures and big day-night temperature changes. These areas have cold-resistant bacteria such as Streptomyces (Actinobacteria) and Bacillus (Firmicutes). These bacteria make special proteins to live in cold environments [5]. In wet Southeast Asian areas with heavy rainfall, some bacteria (such as Pseudomonas spp.) and harmful fungi (such as Colletotrichum spp., which causes anthracnose) grow more because of high soil moisture [5]. Among these local microbial groups, some key root microbes exist in all areas and are closely linked to plant growth. They are the functional core of the root ecosystem. For mango, these key microbes include PGPR such as Bacillus spp. (Firmicutes) and Pseudomonas spp. (Proteobacteria). They make plant hormones (such as indole-3-acetic acid) and break down nutrients. AMF (Glomeromycota, such as Rhizophagus irregularis) also grows with mango roots to help absorb nutrients [6]. These key microbes exist in all regions because their functions (such as nutrient cycling and stress resistance) are necessary for mango growth and yield, no matter the local environment. Besides these key microbes, there are some rare or local microbial groups. Their growth is closely related to local soil and climate. For example, in wet and warm soils of Southeast Asia, Actinobacteria (such as Streptomyces spp.) are more than in other areas. They are closely related to anthracnose control ($r = 0.72$), probably because they make anti-fungal substances in wet conditions [7]. In cold high-altitude soils of Yunnan, some cold-resistant endophytic bacteria (such as Streptomyces spp.) are rare in lowland areas. But they help reduce fruit drop by controlling ethylene production. These rare microbes are not many, but they have special functions to help mango adapt to local environmental stresses. So mango root microbes have a "stable core + local special" pattern. Core microbes meet mango's basic growth needs, while rare microbes help mango adapt to local environments. This structure shows how microbes adapt to different areas, and it also lays a foundation for targeted microbe management in different mango growing areas.

Although root microbes are very important, modern mango farming methods have broken the balance of microbial groups. These methods include overusing chemical fertilizers and pesticides.

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As a result, beneficial core microbes become fewer, harmful germs grow more, and soil health, yield and fruit quality drop. For example, long-term urea use in Hainan reduces soil organic matter, and lowers the number of key nitrogen-fixing bacteria such as Azotobacter and Rhizobium [8]. To help beneficial core microbes grow, we need to keep proper soil pH in different regions (5.0–6.5 for tropical areas, 6.5–7.5 for high-altitude areas) to make microbes work well. We can add organic matter such as compost and biochar to soil, which provides carbon and nutrients for core microbes like PGPR and AMF [8]. We should keep soil moisture at 50–70% of its water-holding capacity to support microbe growth without too much or too little water. We can also use less tillage to protect microbes' living places and their cooperative networks, so microbes become more and work better. We still lack knowledge about how local microbes change and how to manage them.

So we need to study how core and local root microbes affect mango growth and fruit quality. This study aims to find out how root microbial groups (including core and rare microbes) affect mango yield and fruit quality in different regions. We want to find the key microbes that cause fruit quality differences in different areas, and provide scientific support for sustainable and local microbe management in mango farming.

2. Theoretical framework

2.1. Root-zone microorganisms and plant-microbe interactions

Root-zone microorganisms engage in mutualistic, commensal, or pathogenic relationships with mango roots [9]. Beneficial microbes, such as plant growth-promoting rhizobacteria (PGPR) and arbuscular mycorrhizal fungi (AMF), enhance nutrient uptake (e.g., phosphorus and nitrogen), produce phytohormones (e.g., indole-3-acetic acid), and suppress soil-borne pathogens. For instance, PGPR strains Bacillus subtilis and Pseudomonas fluorescens have been shown to improve mango seedling vigor by solubilizing phosphate and producing siderophores [9]. AMF, as demonstrated in high-altitude Yunnan orchards, extend root hydraulic conductivity, mitigate drought stress, and improve fruit set [10]. Root-zone microorganisms form a complex community dominated by functionally critical bacteria and fungi, alongside less abundant archaea and protozoa. Bacterial phyla such as Proteobacteria (e.g., Pseudomonas, Bacillus) and Actinobacteria (e.g., Streptomyces), together with fungal phyla including Glomeromycota (AMF, e.g., Rhizophagus irregularis) and Ascomycota (e.g., Trichoderma), constitute key components. Among these, taxa such as Bacillus, Pseudomonas, and AMF function as cross-regional core microorganisms—consistently present and functionally irreplaceable—whereas Streptomyces and Trichoderma serve as regionally adapted core groups in specific environments, such as high-altitude Yunnan or pathogen-prone Southeast Asia [10]. These core microorganisms drive mango growth through three primary functions: (1) nutrient acquisition—for example, PGPR like Bacillus subtilis solubilize phosphate, and AMF extend hyphae to capture phosphorus and nitrogen; (2) hormone regulation—for example, Bacillus velezensis produces IAA to promote root growth, and cold-tolerant Streptomyces degrades ethylene precursors to reduce fruit drop; and (3) pathogen suppression—for example, Trichoderma asperellum competes with Colletotrichum and secretes antifungals, while Actinobacteria produce antibiotics. The functionality of these microorganisms is often enhanced by inter-taxa synergy—for instance, PGPR-AMF co-inoculation improves nutrient transport—and is shaped by local environmental conditions [10].

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2.2. Regional variations in microbial communities

Soil pH, temperature, water content and organic matter all affect the diversity of microbes. In acidic soils (pH < 5.5), fungi are more common, especially groups in Glomeromycota. In neutral or alkaline soils, bacteria become the main group, including some kinds in Glomeromycota. Fierer et al. [4] pointed out that temperature and rainfall are the main factors that decide the distribution of soil bacteria. This also explains why mango root microbes are different in different areas. The structure of root microbes includes their types, numbers and connection ways, and it shows big differences across regions. Soil traits (pH, organic matter, nutrient level) and climate factors (temperature, rainfall, altitude) lead to these differences [4]. For example, acidic soils in tropical places like Hainan help fungi grow well, such as AMF in Glomeromycota and saprophytic fungi in Ascomycota. Dry lowlands with neutral or alkaline soils have more bacteria, and Proteobacteria and Firmicutes take up over 60% of all bacteria. High-altitude Yunnan has cold-resistant microbes, such as Streptomyces (Actinobacteria) and cold-loving Bacillus. Wet Southeast Asia is good for fast-growing bacteria (like Pseudomonas) and fungi that like moist conditions (like Trichoderma). Climate also changes the substances released by mango roots. For example, cold soils in Yunnan produce more sugar, and Hainan soils with few nutrients release more organic acids. These acids attract local special microbes like fungi that can break down phosphate [4]. But some core microbes exist in all regions as the basic functional group. Core bacteria include common PGPR such as Bacillus (Firmicutes) and Pseudomonas (Proteobacteria). They break down nutrients and make growth hormones. Core fungi are mainly AMF like Rhizophagus irregularis in Glomeromycota, which form stable partnerships with roots to take in phosphorus. These common microbes stay in all areas because their key functions help mango survive. Their functions include recycling nutrients and resisting basic bad conditions, no matter the local environment. Fierer et al. [4] proved this and connected these microbes to basic soil functions, such as breaking down carbon and changing nitrogen into usable forms. This structure keeps a balance between local special traits and stable basic functions for root microbes. Climate also changes the types of microbes. Tropical areas with heavy rain have more fast-growing bacteria that need rich nutrients, while dry areas have microbes that can stand drought [6]. These differences directly change the release patterns of mango roots, which further decide which microbes grow and what functions they perform. In short, soil and climate factors together make mango root microbes different in different regions. Meanwhile, core microbes keep the basic functional stability of the ecosystem, creating a balance between regional specificity and functional conservation. As a result, the microbial groups around mango roots show obvious differences across different regions.

2.3. Relationship between microorganisms and fruit quality

Root-zone microbes influence key mango fruit quality traits directly or indirectly. These traits include sweetness, color, size, aroma and soluble solids content (SSC) [8]. They work by regulating three main physiological processes of mango trees. The processes are nutrient metabolism, stress adaptation and disease defense. These microbes are different in different regions and work together effectively. As core taxa across regions, arbuscular mycorrhizal fungi (AMF) like Rhizophagus irregularis have important functions. In Hainan's acidic soils, they expand the root absorption area through hyphal networks. They change insoluble phosphorus into forms that mango can use. They improve phosphorus absorption efficiency by over 30%. They raise fruit SSC from 14°Brix to 18°Brix. They also increase fruit diameter by about 12% [6]. Plant growth-promoting rhizobacteria (PGPR) like Bacillus velezensis and Pseudomonas fluorescens do two key things. They break down

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inorganic phosphorus and take nitrogen from the air. This helps keep the nutrient balance of mango trees. Actinobacteria make B vitamins and amino acids. These materials are used to make carotenoid and other nutrients. So they improve the nutritional quality of mango. For stress relief, cold-tolerant Streptomyces spp. in Yunnan's high-altitude areas produce ACC deaminase. This substance reduces ethylene build-up at low temperatures (10–15 °C). It cuts fruit drop by 25% and stops pulp from becoming hard [9]. Heat-tolerant fungi in Hainan make osmolytes. These substances fight high-temperature drought and keep SSC stable. Drought-tolerant PGPR in Southeast Asia activate antioxidant enzymes. These enzymes reduce damage from too much water [6]. Root-zone microbes also help mango resist diseases. In Southeast Asia's humid soils, Actinobacteria secrete antibacterial substances. These substances are strongly linked to anthracnose control ($r = 0.72$) [6]. Trichoderma asperellum competes with Colletotrichum gloeosporioides. It also makes mango start its own defense. When used with organic materials in Thai mango orchards, it lowers postharvest anthracnose from 35% to 10% [6]. International studies prove these results. They include papers in Microbiome, ScienceDirect and BMC. These studies show that geographical differences change microbial groups and mango fruit quality. Systematic reviews also explain the working rules of these interactions.

3. Problems in current mango cultivation

3.1. Current problems in mango cultivation

A main challenge of modern mango farming comes from three connected problems. They are unscientific nutrient management, worse soil degradation and a clear drop in soil microbial diversity. These problems together harm soil health, break ecological balance and lower mango yield and fruit quality [11]. The key reason for these troubles is that farmers depend too much on chemical fertilizers and pesticides. People widely use these products to reach short-term production goals. But they bring long-term bad effects to soil ecosystems and microbial functions. Using too many unbalanced chemical fertilizers starts a series of soil degradation. These fertilizers mainly include nitrogen-rich urea, phosphate fertilizers and potassium supplements. In major mango-growing areas such as Hainan, China, farmers use urea for a long time. The annual nitrogen amount is often over 300 kg N/ha. This practice cuts soil organic matter from the fertile 3% to about 1.5% [9]. It also makes soil acidic. Some orchards have pH lower than 5.0. This acidification makes nutrient imbalance worse. It reduces useful micronutrients such as calcium, magnesium and zinc. It also makes nitrate and phosphate flow into deep soil layers. This wastes resources and causes environmental pollution [11]. Overusing phosphate fertilizers leaves insoluble phosphorus in soil. Mango roots cannot take in these phosphorus. They also stop the work of soil enzymes like phosphatases. These enzymes are very important for nutrient cycling. Besides nutrient problems, using many broad-spectrum herbicides and insecticides badly breaks soil microbial balance [11]. For example, herbicides stop the growth of beneficial core microbes. These microbes include PGPR (Bacillus velezensis, Pseudomonas fluorescens) and AMF (Rhizophagus irregularis). Herbicides also reduce the diversity of bacteria and fungi. They help harmful microbes like Colletotrichum gloeosporioides grow more. Farmers use glyphosate for a long time in Hainan mango orchards. This action clearly cuts the number of phosphate-solubilizing bacteria and mycorrhizal fungi in the root zone. It weakens nutrient cycling and mango disease resistance. All these problems show that current mango farming methods have hurt soil health and fruit quality. It is urgent to use sustainable strategies for nutrient and microbial management.

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3.2. Climate-driven shifts in root-zone microorganisms

Climate plays a key role in shaping the structure, function and mango-related interactions of root-zone microbial communities. Changes in temperature, precipitation and altitude directly affect microbial diversity, abundance and metabolic ability across regions [12]. Temperature changes in particular break the stability of microbial groups. In Yunnan's high-altitude mango orchards (over 1,200 m), long cold periods (10–15 °C) lower the colonization rate of AMF by 40% compared with lowland areas [8]. AMF is a core beneficial fungal group. This drop not only weakens phosphorus uptake supported by AMF, but also breaks the symbiotic balance between microbes and mango roots. It leads to delayed flowering and more fruit drop. On the contrary, in tropical areas such as Hainan, long high temperatures (25–35 °C) help heat-tolerant fungi (e.g., saprophytic fungi in Ascomycota) grow and stop cold-adapted bacteria. Finally, root-zone communities become mainly fungi. This shift improves phosphorus solubilization, but also raises the risk of microbial metabolic imbalance caused by heat.

Changes in rainfall also affect microbial activity. In Southeast Asia's humid climates (annual rainfall over 2,000 mm), too much soil moisture helps copiotrophic bacteria (e.g., Pseudomonas in Proteobacteria) and moisture-sensitive pathogenic fungi (e.g., Colletotrichum gloeosporioides, which causes anthracnose) grow. High humidity also reduces oxygen in small soil spaces. It stops helpful aerobic microbes such as Actinobacteria and changes the competitive balance between pathogens and biocontrol microbes [13]. On the other hand, Yunnan's changeable monsoon brings dry and wet periods by turns. Drought periods help drought-tolerant bacteria (e.g., Streptomyces in Actinobacteria) grow but stop AMF hyphae from expanding. Sudden heavy rains break the connection between microbes and mango roots. This lowers the work efficiency of nutrient-transporting microbes. Warm and humid climates in Southeast Asia (e.g., Thailand, Philippines) also help pathogenic fungi such as Colletotrichum gloeosporioides (anthracnose) and Lasiodiplodia theobromae (stem-end rot) grow. Overusing fungicides makes pathogens resistant to drugs and stops helpful microbes. It makes disease outbreaks worse [12].

Altitude stands for mixed climate conditions (lower temperature, higher UV radiation). It leads to special microbial adaptations. High-altitude areas in Yunnan have less total microbial biomass. More cold-tolerant endophytic bacteria (e.g., Streptomyces spp.) live there. These bacteria produce antifreeze proteins and ACC deaminase [14]. They reduce ethylene accumulation in cold weather, but their large number often lowers the diversity of nutrient-solubilizing PGPR such as Bacillus spp.

All these climate-caused microbial changes directly harm mango growth. Less AMF colonization limits nutrient uptake. Fewer beneficial bacteria weaken stress resistance. More pathogenic fungi increase disease risk. All these factors make mango yield and fruit quality different across regions. As Compant et al. [13] stressed, microbial stress caused by climate is not just a passive reaction. It actively affects agricultural productivity. This shows we need climate-adaptive microbial management strategies in mango farming.

3.3. Soil microbial management

Soil microbial management is an important part of modern agriculture. It directly affects soil health, crop growth and environmental sustainability. Sivakumar et al. [15] proved that mixing microbial inoculants (such as Trichoderma) with organic compost can control mango anthracnose effectively. This method reduces the disease rate by 70% in Thai mango orchards. This practice provides an efficient and eco-friendly way to manage diseases in mango cultivation.

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4. Solutions and innovations

To solve the main problems in mango cultivation—including soil degradation, microbial imbalance caused by climate, and the rapid growth of pathogens—targeted new methods focused on microbial control have become effective and sustainable strategies. These methods combine microbial inoculants, climate-adapted strains and integrated disease management (IDM). They help restore soil health, strengthen plants' ability to resist stresses and improve fruit quality in different regions. These strategies use the special functions of core and region-specific microbes. They also adjust measures to fit local soil and climate conditions. In this way, they support both ecological and agricultural sustainability.

4.1. Microbial inoculants for soil restoration

Microbial inoculants are made of groups of beneficial core microorganisms. They play a key role in stopping soil degradation. They can balance microbial communities, improve nutrient cycling and raise soil organic matter (SOM). A four-year field test in Hainan's acidic mango orchards (pH < 5.5) showed the great effect of a tailored microbe group. This group includes plant growth-promoting rhizobacteria (PGPR: Bacillus velezensis Y-1, Pseudomonas fluorescens) and arbuscular mycorrhizal fungi (AMF: Rhizophagus irregularis) [16]. These microbes worked together well. Bacillus velezensis Y-1 produced indole-3-acetic acid (IAA) to help roots grow more. It increased root biomass by 40%. It also made phytase to break down insoluble soil phosphorus. Pseudomonas fluorescens produced siderophores to take in iron and stop harmful fungi such as Fusarium spp. Rhizophagus irregularis grew hyphal networks. These networks could cover 3–5 times more soil than mango roots alone. They helped mango take in more phosphorus and nitrogen. They also stored carbon to increase SOM. The results were very clear. SOM increased by 22% (from 1.5% to 1.83%). The use of fertilizers, especially urea, dropped by 30%. This reduced soil acidification. Mango yield rose from 50,000 kg/ha to 130,000 kg/ha. It was a 160% increase [4]. Fruit quality also improved a lot. Soluble solids content (SSC) went up from 14°Brix to 18°Brix. Fruit diameter increased by 12%. These improvements came from microbial nutrient cycling. It gave mango balanced nitrogen, phosphorus and micronutrients such as zinc and magnesium. Long-term observation also showed good effects. The inoculant group kept soil pH at 5.2–5.5. This reduced aluminum toxicity. Soil enzyme activities became higher: phosphatase by 55%, urease by 38%. Microbial biomass carbon (MBC) rose by 62%. All these showed soil health was restored and productivity stayed high after the test. This method also made microbe functions more stable. It added helpful PGPR but did not change the local microbe living areas. It well solved the problem of too many fungi in Hainan's soil.

4.2. Climate-resilient microbial strains

Choosing microbial strains that fit local climate stresses (such as cold, heat, drought and waterlogging) is an important new method to ease microbial imbalance caused by climate [17]. In Yunnan's high-altitude orchards (over 1,200 m), long cold periods (10–15 °C) stop AMF from colonizing roots and make ethylene build up in plants. Cold-tolerant endophytic Streptomyces strains (collected from local wild mango roots) work very well in this area [9]. These strains make antifreeze proteins (AFPs) to keep cells safe in low temperatures. They also produce ACC deaminase to break down ACC (the material that makes ethylene). This cuts ethylene levels in mango parts by 35%. Field tests show these strains reduce fruit drop by 25%, make flowering come 7 days earlier and raise fruit set rate by 18%. They protect the partnership between AMF and mango

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roots (lifting AMF colonization from 45% to 63%) and help plants take in more phosphorus. For tropical high-temperature areas like Hainan (25–35 °C), people have developed heat-tolerant PGPR including Bacillus amyloliquefaciens H-2. These strains make heat shock proteins (Hsp70) to live in high temperatures. They also give out exopolysaccharides (EPS) to make a protective cover around mango roots. This reduces water loss and damage from heat stress. In Southeast Asia's wet areas (annual rainfall over 2,000 mm), too much water and harmful germs grow easily. Streptomyces hygroscopicus and AMF Rhizophagus clarus form a group that can resist stress. The Streptomyces makes hygromycin to stop water-borne germs such as Phytophthora palmivora. At the same time, AMF makes mango roots turn on aquaporin genes (such as MiPIP2;1). This improves water transport efficiency by 40% and eases leaf yellowing caused by too much water [5]. In all regions, climate-resilient strains are picked from local soil microbes. This makes sure they can fit local environments. It will not break the ecological balance and works well with local microbial groups.

4.3. Integrated Disease Management (IDM)

Instead of only using chemical fungicides, integrated disease management (IDM) uses biocontrol agents, organic materials and farming methods to control harmful germs. It also keeps helpful tiny living things in the soil and solves the main causes of disease outbreaks in areas easy to be affected by pathogens, such as Southeast Asia. The most important part of this method is to mix biocontrol microorganisms with organic materials. In Thai mango orchards, using Trichoderma asperellum TE-7 (a core disease-resistant microorganism) together with compost tea and biochar reduced anthracnose after harvest by 70%, and the incidence rate dropped from 35% to 10% [18]. This mixed treatment works well because of several different working ways. Trichoderma asperellum TE-7 produces special substances to break down the cell walls of Colletotrichum gloeosporioides, the germ that causes anthracnose. It also makes peptaibols to stop the spores of this pathogen from growing. Bacillus velezensis Y-1, which is used with it, makes two lipopeptide antibiotics called iturin and fengycin. These antibiotics target the cell membranes of pathogens and stop pathogens from developing resistance. Organic materials help these biocontrol agents work better. Compost tea provides dissolvable organic matter and micronutrients to help beneficial microorganisms grow, and their population becomes three to five times larger. Biochar made from mango wood works as a support for microorganisms to attach to. It also takes in harmful toxins from pathogens and makes these toxins less effective. Farming methods like crop rotation with legumes (such as Vigna radiata) and reduced tillage make IDM work even better. Legumes can take nitrogen from the air to enrich soil nutrients, which supports the growth of beneficial microorganisms. Less disturbance to soil keeps the living places and thread-like structures of these microorganisms safe. Using IDM for a long time in Southeast Asia brings more extra benefits. The diversity of soil microorganisms increases by 45%, the activity of pathogen resistance genes (like CgMDR1 that is related to fungicide tolerance) drops by 60%, and the shelf life of fruits is made longer by 5 to 7 days [18]. It is worth noting that IDM also reduces the bad unexpected results of chemical fungicides. It restores the number of Actinobacteria, a key group that fights pathogens in wet areas. It also improves the natural ability of soil to stop diseases, so it creates a self-sustaining natural barrier to prevent future disease outbreaks.

5. Results

This study found clear differences in the structure of microbial communities around mango roots and the functions of key root-zone microbes in different mango-growing areas. Microbial

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communities differ by region. Acidic soil in Hainan has more fungi. These fungi help mango trees take in more phosphorus. They also make the soluble solids content (SSC) of mango fruits reach 18°Brix. High-altitude areas in Yunnan have microbial communities with rich bacterial types. Cold-resistant bacteria here lower fruit drop by 25%. Humid regions in Southeast Asia have plenty of Actinobacteria. These bacteria have a strong positive link with anthracnose control ($r = 0.72$). However, bad management in mango farming harms soil health. It breaks the ecological balance, cuts microbial diversity, makes soil degrade faster, and lets pathogens break out more often. Finally, mango yield and fruit quality become lower. So managing microbes is very important to solve these problems. Tests proved that using a key root-zone microbe mix in Hainan's acidic soil works well. The mix includes plant growth-promoting rhizobacteria (PGPR, Bacillus velezensis Y-1) and arbuscular mycorrhizal fungi (AMF, Rhizophagus irregularis). It improves the local root-zone microbial community structure. It also raises mango yield by 160% and makes nitrogen use 40% more efficient. For disease control, using Trichoderma asperellum TE-7 (a key disease-resistant microbe) with organic materials changes the root-zone microbial community structure in Thai mango orchards. It reduces postharvest anthracnose from 35% to 10%. All these results show that soil and climate make root-zone microbial communities different in each area. These differences decide the make-up and functions of key root-zone microbes. These microbes then greatly affect mango growth, yield and disease resistance.

6. Conclusion

Core root-zone microorganisms play a pivotal role in regulating mango growth, yield, and fruit quality across regions, as their composition and functions—shaped by local soil and climate—govern nutrient uptake, stress resilience, and disease resistance. Excessive chemical inputs, climate extremes, and pathogen proliferation disrupt these microbial communities, undermining soil health and crop performance. Targeted interventions—such as microbial inoculants (e.g., Bacillus velezensis Y-1 and Rhizophagus irregularis), climate-adapted strains (e.g., cold-tolerant Streptomyces), and integrated disease management (IDM)—effectively restore microbial balance, enhance yields, and improve fruit quality. Cross-regional conserved core taxa (e.g., PGPR and AMF) provide a functional baseline essential for mango survival, while region-specific taxa complement these functions by adapting to local environmental stresses. Leveraging these microbial traits enables sustainable mango cultivation under changing climatic conditions. Future research should focus on developing region-specific microbial consortia, integrating microbial data with precision agriculture tools (such as soil sensors and artificial intelligence), and promoting policy frameworks for sustainable microbial management to advance the application of core root-zone microorganisms and achieve more efficient, eco-friendly mango production.

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