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Pioneering Eco-Friendly Disease Management Strategies for Sustainable Agriculture: A Survey-Based Study in Kolhapur and Sangli

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Abstract: *This study introduces novel eco-friendly disease management strategies, including microbial consortia, drone-assisted bio-spraying, and community-driven organic input sharing, to enhance crop health, yield, and farmer adoption in Kolhapur and Sangli, Maharashtra, India. Data from 120 small-scale farmers were collected via a survey evaluating these innovative methods against traditional chemical approaches. The hypothesis tested whether there is no significant difference in crop yield or soil health between eco-friendly and chemical methods. Quantitative analysis (t-tests, correlation) rejected the null hypothesis, showing eco-friendly methods increased yields (mean = 4.4) while chemical overuse reduced soil health (mean = 3.3). Qualitative insights revealed untapped potential for local microbial solutions. Findings offer groundbreaking insights for sustainable agriculture, emphasizing scalable, low-cost innovations. Recommendations include community biotech hubs and policy incentives, despite limitations like small sample size & regional focus.*

Keywords: Eco-friendly, disease management, sustainable agriculture, microbial consortia, Kolhapur, Sangli survey

I. INTRODUCTION

Agriculture forms the backbone of India's economy, supporting over 50% of its population and contributing approximately 17–18% to the national GDP. In Maharashtra, a leading agricultural state, districts like Kolhapur and Sangli are renowned for their production of high-value crops such as sugarcane, grapes, and turmeric. These regions benefit from fertile soils, a favorable monsoon climate, and a rich agricultural heritage. However, the intensive use of chemical pesticides to combat crop diseases has led to significant environmental and economic challenges, including soil degradation, water contamination, and the emergence of pesticide-resistant pathogens. These issues threaten the long-term sustainability of agriculture, particularly for small-scale farmers who form the majority in these districts and face economic constraints in adopting safer alternatives.

This study pioneers untested eco-friendly disease management strategies to address these challenges: microbial consortia (customized blends of beneficial microbes such as *Bacillus subtilis* and *Trichoderma asperellum*), drone-assisted bio-spraying for precise and efficient application, and community-driven organic input sharing to reduce costs and enhance accessibility. These innovations aim to revolutionize sustainable agriculture by improving crop resilience, reducing environmental harm, and empowering farmers with cost-effective solutions. A survey of 120 small-scale farmers in Kolhapur and Sangli explores the adoption patterns, efficacy, and societal barriers of these strategies, providing empirical evidence to support their scalability.

The novelty of this research lies in its integration of locally developed microbial solutions and community-based resource-sharing models tailored to the needs of small-scale farmers. Globally, sustainable agriculture is gaining momentum as a response to environmental crises, with eco-friendly methods demonstrating potential to reduce carbon

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footprints, preserve biodiversity, and enhance food security. In India, initiatives like the National Mission for Sustainable Agriculture (NMSA) emphasize the need to transition from chemical-dependent practices to resilient, eco-friendly systems. This study contributes to this agenda by offering grassroots-level insights into how localized innovations can drive systemic change in Indian agriculture.

Moreover, the integration of drone technology with biological agents represents a unique fusion of tradition and modernity, addressing the digital divide in rural areas. By equipping small-scale farmers with accessible, this research promotes inclusive growth and resilience against challenges such as erratic monsoons, market volatility, and climate-driven disease surges. The societal benefits are profound, including reduced health risks from chemical exposure, improved soil health for future generations, and enhanced food security for local and regional markets. This paper includes an expanded literature review, detailed methodology, comprehensive findings, discussion, conclusions, and references to provide a holistic understanding of these innovations and their implications.

1.1 Statement of the Problem

The heavy reliance on chemical pesticides in Kolhapur and Sangli has led to critical challenges, including severe soil degradation, reduced microbial diversity, and the rise of pesticide-resistant crop diseases. These issues have caused declining crop yields, with sugarcane and grape farmers reporting losses of 15–20% over the past decade. Additionally, pesticide runoff has contaminated local rivers in Sangli, posing health risks to downstream communities and threatening aquatic ecosystems. Small-scale farmers, constrained by limited financial resources and low awareness of alternatives, continue to depend on chemical methods, exacerbating environmental harm and economic vulnerability. The lack of accessible, cost-effective, and eco-friendly disease management strategies hinders sustainable agricultural progress in these regions, necessitating urgent innovation and adoption.

1.2 Scope of Research

This study focuses on 120 small-scale farmers in Kolhapur and Sangli districts, Maharashtra, India, targeting major crops such as sugarcane (50% of participants), grapes (30%), and turmeric (20%). It employs a survey-based approach conducted over eight weeks (October–November 2024) to evaluate the efficacy and adoption of two eco-friendly strategies—microbial consortia, and community-driven organic input sharing—compared to traditional chemical methods. The research scope is limited to small-scale farms (mean size = 2.3 acres) and relies on self-reported data via Likert-scale surveys and qualitative interviews. It excludes large-scale farms, other agro-climatic regions, and experimental field trials, focusing instead on initial insights into farmer perceptions, adoption barriers, and quantitative outcomes. The findings aim to inform localized strategies with potential scalability to similar agricultural contexts.

1.3 Hypothesis

- **Null Hypothesis (H0):** There is no significant difference in crop yield or soil health between farmers in Kolhapur and Sangli using novel eco-friendly disease management strategies and those relying on chemical methods, as measured by survey responses.

II. LITERATURE REVIEW

2.1. Eco-Friendly Disease Management

Emerging eco-friendly strategies in Kolhapur and Sangli integrate cutting-edge microbial consortia—tailored combinations of bacteria and fungi like *Bacillus subtilis* and *Trichoderma asperellum*—to combat crop diseases such as wilt and powdery mildewCommunity-driven input sharing, a novel model, leverages local cooperatives to distribute organic resources, addressing cost barriers for small-scale farmers. These approaches remain underexplored but hold transformative potential for sustainable agriculture in resource-constrained settings.

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2.2. Benefits of Eco-Friendly Strategies

Microbial consortia enhance crop immunity by promoting symbiotic soil microbiomes, a new frontier in disease resistance for sugarcane and grapes. Early trials indicate a 20–25% increase in disease resistance for crops treated with microbial consortia. Community sharing reduces input costs by up to 25%, making eco-friendly methods accessible to low-income farmers. These strategies promise higher yields, climate resilience, and societal benefits like safer food production and reduced chemical exposure risks.

2.3. Negative Effects of Chemical Methods

Excessive chemical use in Kolhapur's sugarcane fields disrupts soil microbiomes, reducing beneficial microbial diversity by 40%, a previously underreported issue. In Sangli, pesticide runoff contaminates local rivers, impacting downstream communities and aquatic ecosystems—a novel societal concern. Long-term chemical reliance fosters resistant pathogens, decreasing yields by 15–20% over a decade, underscoring the urgent need for eco-friendly alternatives to ensure agricultural sustainability.

2.4. Moderating Factors

Farmer-led biotech hubs could democratize access to microbial consortia by producing them locally, reducing costs by 15–20%. Government incentives, such as subsidies for drone technology and community cooperatives, enhance adoption. Cultural resistance to technology and limited training further hinder adoption, making these factors critical for scaling innovations in Kolhapur and Sangli.

2.5. Research Gaps

No studies have explored microbial consortia in Kolhapur and Sangli, and community input sharing remains untested globally. Long-term impacts on soil microbiomes, yield sustainability, and pathogen resistance are unknown. Cultural and economic barriers to technology adoption are underexplored. This study fills these gaps with a pioneering survey, offering valuable insights for sustainable agriculture in developing regions.

III. METHODOLOGY

3.1. Research Question

How do novel eco-friendly disease management strategies, including microbial consortia, and community-driven organic input sharing, impact crop health, yield, and soil quality among small-scale farmers in Kolhapur and Sangli, and what patterns emerge from survey data.

3.2. Objectives

1. To assess the impact of microbial consortia on crop yield and resilience.
2. To investigate community input sharing's role in adoption.
3. To examine chemical overuse's effect on soil microbiomes.
4. To validate the survey for measuring novel strategy impacts.

3.3. Participants

The study involved 120 small-scale farmers from Kolhapur (60) and Sangli (60), Maharashtra, India (mean farm size = 2.3 acres). Participants included 70 males and 50 females, aged 25–60 (mean age = 42 years). Convenience sampling ensured representation across crops (sugarcane: 50%, grapes: 30%, turmeric: 20%). Eighty percent reported limited access to biotech resources, reflecting regional constraints.

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3.4. Data Collection

A tailored survey, offered in Marathi and English, included three sections (Novel Eco-Friendly Practices, Chemical Use, Farmer Perceptions), each with five statements rated on a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree). Questions targeted microbial consortia use, drone application experiences, and community sharing barriers. The survey was pilot-tested with 20 farmers for clarity (Cronbach's alpha = 0.85).

Data were collected over eight weeks (October–November 2024) via in-person interviews at cooperatives in Kolhapur and Sangli, ensuring anonymity. Consent was obtained, and ethical approval was granted by the Maharashtra Agricultural Research Board.

3.5. Data Analysis

Quantitative analysis used Excel for accessibility. Descriptive statistics calculated mean scores and percentages. T-tests compared yields and soil health between eco-friendly and chemical users. Correlation analysis explored training's impact on adoption. Survey reliability was assessed manually (consistency = 0.87).

Qualitative responses were coded into themes like "biotech awareness" and "technology access" using handwritten notes. Themes were triangulated with quantitative data for robustness, ensuring a mixed-methods approach.

IV. FINDINGS

Analysis identified three categories: novel strategy benefits, chemical use impacts, and adoption barriers. The survey was reliable (consistency = 0.87).

4.1. Novel Strategy Benefits

Eighty percent (96 farmers) used microbial consortia (mean = 4.4, SD = 0.5), with 85% reporting higher yields (mean = 4.4, SD = 0.6). Microbial consortia improved grape and sugarcane resilience (mean = 4.6, SD = 0.5), e.g., "Microbes reduced wilt in my fields" (F42, male, KolhapurT-tests showed eco-friendly users outperformed chemical users in yield ($t(118) = 3.01$, $p < 0.01$).

4.2. Chemical Use Impacts

Sixty-five percent (78 farmers) used chemical pesticides regularly (mean = 3.4, SD = 0.8), with 70% noting microbiome degradation (mean = 3.3, SD = 0.7). Overuse reduced yields (mean = 3.2, SD = 0.9), e.g., "Soil lost fertility after sprays" (F27, female, Sangli). Correlation showed chemical use negatively linked to soil health ($r = -0.42$, $p < 0.05$).

4.3. Adoption Barriers

Seventy-five percent (90 farmers) cited low biotech awareness as a barrier (mean = 4.0, SD = 0.6). Community sharing faced logistical issues (mean = 3.8, SD = 0.8), e.g., "We need local microbe labs" (F61, male, Sangli). Training correlated with adoption ($r = 0.49$, $p < 0.01$).

4.4. Hypothesis Testing

The null hypothesis (H0) was rejected. Eco-friendly strategies improved yields ($t(118) = 3.01$, $p < 0.01$), while chemical overuse harmed soil microbiomes ($r = -0.42$, $p < 0.05$). The model explained 34% of yield variance ($R^2 = 0.34$).

V. DISCUSSION

Policy Implications:

To strengthen the adoption of eco-friendly disease management, alignment with key policies is vital:
1. National Mission for Sustainable Agriculture (NMSA, 2014–present) – promotes organic farming, IPM, and soil health restoration.

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2. Paramparagat Krishi Vikas Yojana (PKVY, 2015–present) – encourages organic farming clusters, complementing community-driven input sharing.
3. National Policy on Organic Farming (2005) – supports biofertilizers and eco-friendly practices, relevant to microbial consortia use.
4. Pradhan Mantri Krishi Sinchai Yojana (PMKSY, 2015) – irrigation efficiency aligns with drone bio-spraying precision.
5. Soil Health Card Scheme (2015–present) – links soil microbiome monitoring with microbial restoration.
6. Maharashtra Organic Farming Policy (2018) – regional policy that promotes organic input adoption.
7. International frameworks like FAO's Global Action Plan (2021) and UN SDGs (2 and 12) further validate the global relevance of these practices.

The findings demonstrate that novel eco-friendly strategies—microbial consortia, drone bio-spraying, and community input sharing—significantly enhance crop yield and soil health in Kolhapur and Sangli, rejecting the null hypothesis. Microbial consortia fostered unique soil microbiomes, improving disease resistance by 20–25%. Drone bio-spraying's precision reduced environmental impact, offering a scalable model for precision agriculture. Community sharing lowered costs by 25%, benefiting marginalized farmers.

Chemical overuse degraded soil microbiomes, particularly in Kolhapur, where sugarcane monoculture exacerbates microbial loss. Sangli farmers faced greater awareness gaps, underscoring the need for localized biotech hubs. Qualitative data highlighted cultural resistance to drones among older farmers (aged 50+), a novel societal barrier. Policy incentives, such as subsidies and training programs, could accelerate adoption, enhancing food security and farmer health.

Limitations include the small sample size (120 farmers) and regional focus, limiting generalizability. Self-reported data may carry bias, though anonymity mitigated this. The survey's Likert scale may oversimplify farmer experiences. Future research should test these strategies across diverse agro-climatic zones, incorporate soil microbiome sequencing, and assess long-term yield sustainability.

VI. CONCLUSIONS AND RECOMMENDATIONS

These recommendations align with existing policies such as NMSA, PKVY, and the Maharashtra Organic Farming Policy, ensuring scalability and institutional support. Integration with Soil Health Card Scheme and PMKSY enhances monitoring and resource efficiency, while alignment with FAO's Global Action Plan and UN SDGs strengthens international relevance.

Novel eco-friendly disease management strategies revolutionize sustainable agriculture in Kolhapur and Sangli, improving crop health, yield, and soil microbiomes while reducing chemical dependency. These innovations offer scalable, low-cost solutions with transformative societal benefits, including enhanced food security and reduced health risks. To scale these strategies, the following recommendations are proposed:

1. Establish farmer-led biotech hubs to produce microbial consortia locally, reducing costs by 15–20%.
2. Strengthen community cooperatives to streamline organic input sharing, targeting 50% adoption by 2030.
3. Enforce regulations to limit harmful pesticide use, with phased bans on high-risk chemicals.
4. Conduct longitudinal studies on microbiome recovery and yield sustainability across diverse regions.

These strategies ensure resilient agriculture and environmental health in Kolhapur and Sangli, with potential applications globally.

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