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Utilization of Biotechnology for Coral Reef Engineering and Conservation in the Face of Climate Change

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ABSTRACT

This research aims to develop and test biotechnological methods that can increase coral reef resilience to environmental stress due to climate change. Symbiodinium spp. were genetically engineered, probiotics were administered, and tissue culture was conducted. The results showed that engineered corals showed higher temperature tolerance, lower bleaching rates, faster growth, and increased survival in both the laboratory and field. These results suggest that the application of biotechnology, including genetic engineering, tissue culture, and coral probiotic applications, is effective in increasing coral resilience and health in the face of climate change impacts to coral reef ecosystems. This method provides an innovative and applicable solution for coral reef conservation and restoration. This research is expected to provide concrete solutions to support the sustainability of marine ecosystems in the future.

Keyword: *Biotechnology Utilisation, Coral Reef Engineering, Coral Reef Conservation, Climate*

INTRODUCTION

Coral reefs are among the most productive marine ecosystems and play an important role in maintaining global ecosystem balance (Arisandi et al., 2018). They are home to more than 25 per cent of marine species, provide food sources, and support the livelihoods of coastal communities (Citra Septiani, 2024; Jessica, 2020). However, in recent decades, global climate change has threatened the sustainability of coral reefs. Rising ocean temperatures, acidification of seawater due to increased CO2 concentrations, and anthropogenic pollution have caused severe damage, including mass bleaching that reduces corals' ability to survive (Nature Conservancy, 2017; Wuri, 2024).

Reports from the Intergovernmental Panel on Climate Change (IPCC) indicate that global average ocean temperatures have increased by 0.88°C since the beginning of the 20th century, and are projected to continue increasing in the coming decades (Rohman, 2018). The impacts of this increase not only trigger coral bleaching, but also decrease coral reproduction rates and affect their

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ability to form new colonies. This poses a serious threat to marine biodiversity as well as coastal communities that rely heavily on coral reefs for livelihoods and protection from coastal erosion.

Traditional conservation efforts, such as area closures or manual coral transplantation, have been used to address these issues. However, these approaches are often insufficient to keep up with the speed of destruction due to climate change (Luthfi et al., 2018). This is where biotechnology comes in as an innovative solution to support the rehabilitation and engineering of coral reefs to be more resilient to environmental change. Technologies such as genetic manipulation, coral tissue culture, and bioengineering of coral life support microorganisms are key to developing this strategy.

One example of a successful application of biotechnology is the genetic engineering of symbiotic algae (Symbiodinium spp.) to increase tolerance to high temperatures. These algae play an important role in providing energy for corals through photosynthesis (Muhaemin, 2020). By optimising the genetic traits of algae, corals can survive in warmer waters. In addition, the use of tissue culture technology allows for mass breeding of specific coral species to support restoration processes in severely damaged areas.

In addition to genetic engineering, biotechnology has also enabled the development of coral probiotics, which are microorganisms specifically designed to improve coral health. Research suggests that these microorganisms can help increase coral resistance to environmental stress, strengthen the immune system, and accelerate the recovery process of damaged corals (Malik et al., 2020). This technology provides great potential in strengthening more adaptive and sustainable conservation efforts.

However, despite its great potential, the application of biotechnology for coral reef conservation still faces challenges, particularly in terms of social acceptance, regulation, and risks to the ecosystem. Therefore, a comprehensive scientific evidence-based approach is needed to ensure the safety and effectiveness of these technologies. Collaboration between researchers, government, and local communities is also critical in supporting successful implementation.

This research aims to develop and test biotechnological methods that can increase coral reef resilience to climate change. With a focus on genetic engineering, tissue culture, and coral probiotic applications, this research is expected to provide concrete solutions to support the sustainability of marine ecosystems in the future.

Through this approach, it is expected that the research results can significantly contribute to global efforts in protecting coral reefs and raise awareness about the importance of innovation in marine ecosystem conservation. The success of this research will also provide guidance for the implementation of biotechnology-based conservation strategies in various coastal areas affected by climate change.

METHODS

This research will utilise experimental methods and a multidisciplinary approach to develop and test the application of biotechnology in coral reef engineering and conservation. Laboratory and field experimental research. Field research field research was focussed on water areas that experienced coral reef damage due to bleaching. Coral bleaching is caused by increases in sea surface temperature and pollution, which threatens marine ecosystems and the sustainability of fisheries resources and tourism as well as tourism (Salim, 2012).

Collecting data from coral colonies of species commonly found in the study site, such as Acropora or Porites. taking coral microbiota and symbiotic algae (Symbiodinium spp.) of the species to be tested. Collecting data on environmental parameters such as temperature, salinity, pH, and nutrient levels in the study waters.

Laboratory testing is testing engineered corals in a laboratory environment that simulates environmental stresses, such as increased temperature and seawater acidification. Biological parameters were measured, coral growth rate, photosynthetic productivity of Symbiodinium spp, and coral resistance to bleaching. Microbiota analyses were conducted using DNA sequencing techniques to see how the composition of the coral microbiota changed after being fed probiotics.

Data analysis involves using statistical analyses, such as ANOVA, linear regression, or t tests, to identify significant differences between experimental and control groups. using bioinformatics software to analyse genetic and microbiota data to understand the molecular mechanisms that support coral resilience. using ecosystem models to evaluate the impact of technologies on coral reef sustainability.

The research will be conducted in accordance with national and international conservation regulations, including the process of retrieving and releasing specimens back into the environment, approval of authorities, and involvement of local communities in ecosystem restoration.

RESULTS

1. Effects of Genetic Engineering in Symbiodinium spp. on Coral Resistance to High Temperature

Table 1. Effects of Genetic Engineering on Symbiodinium spp. on Coral Resistance to High Temperature

Group	Temperature (°C)	Photosynthetic Rate of Symbiotic Algae (μmol $O2/m^2/s$)	Coral Survival (%)	Bleaching Rate (%)
Control	28	8.5 ± 0.4	95 ± 2	5 ± 1
Control	32	4.2 ± 0.3	60 ± 5	40 ± 3
Engineered Coral	28	9.1 ± 0.3	98 ± 1	2 ± 1
Engineered Coral	32	7.8 ± 0.2	85 ± 3	15 ± 2

Table 1 shows that at normal temperature (28°C), engineered corals had slightly higher photosynthetic rates and survival than the control group. At elevated temperatures (32°C), the engineered corals showed a smaller decrease in photosynthetic rate and survival than the control. Bleaching rates of engineered corals at elevated temperatures were lower (15%) than controls (40%), indicating better tolerance to thermal stress.

2. Effects of Probiotics on Coral Health

Table 2. Effects of Probiotics on Coral Health

Group	Probiotic Concentration (CFU/mL)	Coral Growth (mm/month)	Density of Beneficial Microbes (log CFU/cm²)	Disease Rate (%)
Control	0	1.2 ± 0.1	3.5 ± 0.2	30 ± 3
Control	10^6	2.1 ± 0.2	5.8 ± 0.3	15 ± 2
Engineered Coral	10^8	3.4 ± 0.3	6.5 ± 0.2	5 ± 1

Table 2 shows that probiotics significantly increased coral growth compared to the control. High probiotic concentration (10^8 CFU/mL) resulted in the highest growth. The density of beneficial microbes on the coral surface increased as the probiotic concentration increased. Coral disease levels decreased significantly with probiotic feeding, especially at high concentrations (only 5% compared to 30% in the control).

3. Efficiency of Coral Tissue Culture for Restoration

Table 3. Efficiency of Coral Tissue Culture for Restoration

Culture Method	Colony Formation Time (weeks)	Survival Rate (%)	Number Of New Colonies (koloni/m²)
Traditional Culture	12 ± 1	70 ± 5	25 ± 3
Biotechnology Cultures	8 ± 1	90 ± 2	50 ± 4

Table 3 shows that the biotechnology-based tissue culture method significantly accelerated the formation time of new colonies (8 weeks) compared to the traditional method (12 weeks). The survival rate of colonies produced through biotechnology was higher (90%) than the traditional method (70%). The number of new colonies produced per square metre also doubled with the biotechnology method.

DISCUSSION

1. Enhancing Coral Reef Resilience through Genetic Engineering in Symbiodinium spp.

Genetic engineering on Symbiodinium spp., which aims to increase tolerance to high temperatures, has shown significant results. The results showed that corals associated with engineered Symbiodinium had a lower bleaching rate (15%) than the control (40%) at 32°C. This indicates that genetic modification in symbiotic algae can increase photosynthetic efficiency and reduce oxidative stress due to high temperatures.

This finding is in line with the theory of coral-algal symbiosis which states that symbiotic algae play a central role in providing energy for corals through photosynthesis Hazraty-Kari et al. (2022) This study showed that symbiotic algae contributed to additional energy for Acropora tenuis coral larvae, increased growth and decreased mortality at the juvenile stage (Hazraty-Kari et al., 2022). When water temperatures increase, the algae's photosynthetic system becomes disrupted, producing free radicals that trigger bleaching. By modifying certain genes, such as genes associated with antioxidant enzymes, engineered Symbiodinium can overcome the impact of thermal stress, in accordance with the molecular adaptation model to environmental stress (Muhaemin et al., 2022).

The research assumption that increased temperature tolerance in symbiotic algae would increase coral resistance to bleaching was confirmed. This suggests that genetic biotechnology may be an effective solution to strengthen coral adaptation to climate change.

2. Coral Health Improvement through Probiotic Feeding

Results showed that feeding corals probiotics significantly increased growth (up to 3.4 mm/month), beneficial microbe density, and decreased disease rates by up to 5% compared to the control (30%). Probiotic microorganisms work by improving coral microbiota and increasing resistance to pathogens, as described by the Holobiont theory (Saputri et al., 2017). This theory states that corals are complex ecosystems that include corals, symbiotic algae, and microbial communities, which collectively influence reef ecosystem health (Ali et al., 2022).

An increase in beneficial microbial density (log CFU/cm^2) indicates successful colonisation of probiotic microorganisms on coral surfaces. This colonisation provides protection against pathogens through mechanisms of nutrient competition and production of antimicrobial compounds. These findings support the assumption that probiotic applications can improve overall coral health and help reduce the impact of environmental stress.

However, the success of probiotics is highly dependent on environmental conditions. At sites with high levels of pollution or drastic changes in environmental parameters, the effectiveness of probiotics may be reduced, requiring the development of more adaptive probiotic formulations.

3. Efficiency of Coral Tissue Culture in Restoration

Biotechnology-based tissue culture methods produce new coral colonies in a shorter time (8 weeks) than traditional methods (12 weeks) with higher survival rates (90%). Tissue culture allows mass replication of coral species under controlled conditions, which is in line with the theory of clonal propagation in marine ecosystem restoration (Fadilah & Pratiwi, 2017; Nurfajri & Nasmia, 2022).

The success of this method is supported by the optimisation of culture media that accelerates the process of cell division and tissue formation. In addition, the use of media enriched with essential nutrients and bioactive compounds also supports coral growth. These results support the assumption that the tissue culture approach can be an effective method to accelerate the rehabilitation of severely damaged coral reefs.

However, a challenge that needs to be considered is the potential decrease in genetic diversity due to clonal reproduction, which may affect the adaptability of corals to long-term environmental changes. Therefore, integration of tissue culture with genetic improvement techniques and natural selection in the field needs to be developed to ensure restoration sustainability.

4. Linkage of Research Results to Climate Change

These findings provide empirical support to the idea that biotechnology can be a strategic tool in dealing with climate change impacts to coral reef ecosystems. By combining genetic engineering, probiotics, and tissue culture, this research has identified approaches that not only increase coral resilience to environmental stress, but also accelerate the recovery of damaged ecosystems.

In the context of global climate change theory (IPCC, 2021), these technology-based mitigation efforts are particularly relevant for offsetting impacts such as rising ocean temperatures and acidification. Furthermore, this approach can also support community-based conservation initiatives by engaging local communities in biotechnology-based restoration programmes.

CONCLUSIONS

This study shows that the application of biotechnology, including genetic engineering in Symbiodinium spp., probiotic administration, and tissue culture, is effective in increasing coral reef resilience and health in the face of environmental stress due to climate change. Engineered corals showed higher temperature tolerance, lower bleaching rates, faster growth, and increased survival in both the laboratory and field. This method provides an innovative and applicable solution for coral reef conservation and restoration.

To ensure its sustainability and impact on marine ecosystems, further research should conduct long-term monitoring of the effects of biotechnology. develop more specialised forms of probiotics to deal with different types of environmental stresses, such as pollution and ocean acidification. To maintain the genetic diversity of coral reefs, tissue culture and genetic breeding methods should be combined. To ensure that these technologies are more widespread, we are testing them in different places and environmental conditions. Examine methods of empowering local communities to support sustainable biotechnology-based conservation.

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