

I. INTRODUCTION

1.1. Background

The Lapindo mudflow was an environmental disaster that occurred in Sidoarjo Regency, East Java, Indonesia, in 2006. This disaster involved the eruption of gas and mud at a high temperature of 100°C from the surface of the ground at . As a result of this hot mudflow, 3 subdistricts and 12 villages were submerged in hot mud. The subdistricts affected by the hot mudflow include Porong Subdistrict, Jabon Subdistrict, and Tanggulangin Subdistrict, which were submerged in hot mud, while the 12 villages affected by the hot mudflow include Renokenongo Village, Glagaharum Village, Pamotan Village, Gedang Village, Wunut Village, Besuki Village, Kedungcangkring Village, Pejarakan Village, Kedungbendo Village, Gempolsari Village, Ketapang Village, and Kalitengah Village (*et al.*, 2023) . This disaster originated from a project by PT. Lapindo Brantas, which was exploring for oil reserves. According to Priambodo *et al.*, (2023) , *an underground blowout* occurred during the drilling process.

The Lapindo mudflow disaster has had negative impacts in various areas, including physical, social, economic, psychological, and environmental impacts (Alfina *et al.*, 2024). This damage includes infrastructure damage, damage to forests and farmland, loss of livelihoods or jobs and a decline in income, as well as serious environmental damage, including water and soil contamination. Research findings by Purnomo & Rachmadiarti (2018), indicate that ecosystem contamination caused by the Lapindo mudflow has led to changes in the surrounding environment, and that the mudflow has resulted in a decline in the biodiversity of organisms in the affected area. Suning (2012), states that the Lapindo mudflow disaster has led to a decline in soil quality, which in turn affects agricultural activities in the region specifically, a decrease in both the quality and quantity of crop yields, resulting in crop failures. One consequence of the Lapindo mudflow on soil quality is increased soil salinity in the affected areas.

Salinization, or salinity, is a process in which the concentration of easily soluble salts in the soil increases, resulting in saline soil that is, soil with a high salt content (Karolinoerita & Annisa, 2020) . According to Zaman *et al.*, (2018) , saline

soil forms from the accumulation of salts primarily NaCl, Na₂SO₄, CaCO₃, and MgCO₃. There are several causes of high soil salinity. According to Sihotang (2021), soil salinity can result from seawater intrusion, irrigation water containing salt particles, high evaporation rates coupled with low rainfall which causes salts to rise into the root zone or natural disasters. Based on research conducted by (Karjono, 2013), it is stated that the area affected by the Lapindo mudflow has high salinity levels this is evident from laboratory analysis results showing a sodium content in the mud of 65.43 me/100 g. Electrical Conductivity (EC) analysis results also indicate a high value of 25.7 dS/m.

Saline soil reduces a plant's ability to absorb water, thereby hindering optimal growth and development if this condition persists, it will lead to decreased crop productivity. High soil salinity affects root development, making it difficult for roots to absorb water. Additionally, soil salinity causes plants to undergo *plasmolysis* a process in which plant cells lose water through osmosis into the soil solution, which has a much higher salt concentration than the fluid inside the cells (hypertonic) This results in water being drawn out of the plant cell's vacuole, causing the cell to shrink and the plasma membrane to detach from the cell wall. According to *et al.*, (2024), high soil salinity also causes ionic stress or is toxic to plants. Furthermore, saline soil causes plants to experience osmotic stress and secondary stress. Therefore, efforts are needed to reduce soil salinity to support optimal plant growth and development, one of which is by utilizing bacteria and plants that act as bioremediators.

Bioremediation is the restoration of a contaminated environment by utilizing organisms or microorganisms such as bacteria, fungi, viruses, and plants to break down and neutralize pollutants that are harmful to the surrounding environment. *Calvina et al.*, (2024) state that bioremediation is a biological process that utilizes microorganisms or plants capable of removing or neutralizing pollutants in a contaminated environment. According to *Prasidya et al.*, (2022), bioremediation is a natural effort to restore or eliminate pollutants that are harmful to the environment. The bioremediation process can utilize agents capable of reducing harmful pollutants in the surrounding environment, one of which is the use of microorganisms such as the bacterium *Bacillus* spp.

Bacillus spp. bacteria are one type of bacteria that can function as biological control agents (BCAs) because they are capable of suppressing the growth of other pathogens that cause plant diseases. Setiaji *et al.*(2023) state that *Bacillus* spp. are bacteria capable of acting as biological control agents because they are adaptable, capable of forming endospores, and tolerant of various environmental conditions. Furthermore, *Bacillus* spp. can survive in a wide variety of habitats. According to Handayani, & Vidia, and(2023), *Bacillus* spp. are bacteria that can be found in various locations. Research conducted by Azzahra *et al.*, (2025) identified four *Bacillus* spp. isolates found in mangrove roots. One of these was *Bacillus* spp. isolate A-10, which is capable of surviving in mangrove roots and exhibits antagonistic properties by forming a 19-mm inhibition zone against *Ralstonia solanacearum*, the bacterium responsible for bacterial wilt in plants. Another study conducted by Moekti *et al.*, (2025) identified three *Bacillus* spp. isolates found on mangrove leaves. One of these was *Bacillus* spp. isolate D-28, which is capable of surviving on mangrove leaves and exhibits antagonistic properties by forming a 12.5 mm inhibition zone against the fungus *Alternaria* sp., the causative agent of leaf spot in plants. Samardi *et al.*, (2021) state that the results of the exploration and identification of *Bacillus* spp. bacteria on mangrove plants indicate they can survive at pH levels ranging from 4 to 10, and can survive under various salinity conditions (NaCl 0–6%). *Bacillus* spp. Results of exploration and identification Purnawati & Nirwanto,(2021) identified a *Bacillus* spp. isolate from eggplant plants and designated it as isolate Bth-22. At concentrations of 10% to 15%, the *Bacillus* spp. isolate Bth-22 was able to suppress pathogen infection in corn seeds by 56.7% and 53.3% (*et al.*, 2024) . *Bacillus* spp. also possess bioremediation capabilities because these bacteria form endospores and exhibit diverse antagonistic mechanisms (Mendrofa & Lase, 2025) . Endospores are bacterial structures capable of surviving in a wide range of environmental conditions, including harsh or unsuitable environments (Romadloni *et al.*, 2024) therefore, *Bacillus* spp. bacteria are often used for the bioremediation of contaminated environments.

Bacillus spp. bacteria are known as bioremediation agents because they have the ability to degrade organic pollutants by capturing or absorbing (biosorption) these compounds into their cells and utilizing them for enzymatic

activity (Aznur *et al.*, 2022) . *Bacillus* spp. bacteria are also halotolerant, meaning they can survive in soils with both high and low salinity (et *al.*, 2024). Research conducted by Silvia, (2025) shows that *Bacillus* spp. bacteria have the ability to reduce saline soil pollutants by up to 19%. Sunita *et al.*, (2020) state that *Bacillus* spp. is one of the bacteria effective in reducing soil salinity. There are also plants that have the ability to lower soil salinity; one such plant is red amaranth (*Amaranthus tricolor* L.).

Red spinach (*Amaranthus tricolor* L.) is a horticultural crop that is widely cultivated in Indonesia. This plant is rich in vitamins, including antioxidants such as betalains, carotenoids, vitamin C, flavonoids, and polyphenols, which are beneficial for human health (Wiyasihati & Wigati, 2016). Additionally, this plant can thrive in saline soil conditions (Widawati *et al.*, 2016). Research conducted by Halim (2020) states that red spinach can thrive in soil with high salinity levels of up to 8,000 ppm NaCl. Red spinach can survive in saline soil by minimizing water use, maintaining turgor pressure, and synthesizing enzymatic and non-enzymatic compounds (Prabowo & Rachmawati, 2020) . Compounds produced by red spinach plants to reduce soil salinity in contaminated areas include enzymes such as *glutathione*, *ascorbic acid*, *carotenoids*, and *flavonoids*. Additionally, the enzymes produced by red spinach plants help maintain the balance of *Reactive Oxygen Species* (ROS) within cells (Chutipaijit *et al.*, 2009) . The compounds produced by red spinach plants can reduce soil salinity, thereby yielding positive results for soil health and plant growth.

1.2. Research Question

Based on the background described above, the research question for this study is as follows:

1. Do *Bacillus* spp. bacteria from various isolate sources have the ability to reduce soil salinity?
2. Do red amaranth plants (*Amaranthus tricolor* L.) have the ability to reduce soil salinity?
3. Does a combination of *Bacillus* spp. bacteria and red amaranth (*Amaranthus tricolor* L.) have the ability to reduce soil salinity?

1.3. Research Objectives

The objectives of this study are as follows:

1. To determine the ability of *Bacillus* spp. bacteria from various isolate sources to reduce soil salinity.
2. To determine the ability of red amaranth (*Amaranthus tricolor* L.) to reduce soil salinity
3. To determine the ability of a combination of *Bacillus* spp. bacteria and red amaranth (*Amaranthus tricolor* L.) to reduce soil salinity

1.4. Research Benefits

The results of this study are expected to provide scientific information regarding the ability of *Bacillus* spp. bacteria from various isolates and red amaranth (*Amaranthus tricolor* L.) to reduce soil salinity in areas affected by the Lapindo mudflow in Sidoarjo. Scientifically, this study is expected to contribute to the advancement of knowledge, particularly in the field of agriculture. Socially, this study is also expected to offer farmers an environmentally friendly alternative for reducing soil salinity on cultivated land in the areas affected by the Lapindo mudflow in Sidoarjo, without causing harmful residues in the surrounding environment.