Chapter 1

Introduction

1.1 Background

Cellulose, the most abundant natural biomaterial on Earth, has attracted attention in biomedical research due to its versatility and favorable physicochemical properties (Hasanin, 2022). Derived from diverse biological sources including plants, algae, and bacteria, cellulose can be engineered into advanced functional materials such as scaffolds, porous membranes, hydrogels, and wound dressings. Its biocompatibility, mechanical strength, and ionic properties makes it particularly valuable for tissue engineering and regenerative medicine applications (Cheng et al., 2023). However, conventional cellulose production primarily depends on lignocellulosic biomass, particularly wood, raising environmental challenges, including deforestation, ecosystem imbalance, and competition for arable land; issues that are increasingly incompatible with sustainable development goals (Zanchetta et al., 2025).

In response to these challenges, marine macroalgae (seaweeds) have emerged as a promising source for sustainable cellulose production. Unlike terrestrial biomass, macroalgae contain little to no lignin, allowing for cellulose extraction through milder processing conditions while maintaining high purity and minimal chemical degradation (Li et al., 2025). In addition to their environmental advantages, macroalgae are abundant, fast-growing, and widely distributed along global coastlines, making them an attractive biopolymer resource for circular economy development (Machado et al., 2024).

This opportunity is particularly relevant in Indonesia, recognized as one of the world's major marine biodiversity hotspots and the second-largest producer of macroalgae globally. Home to more than 2,000 species of algae, including both microalgae and macroalgae, Indonesia contributes approximately 28% of global production and over 60% of its national aquaculture output (Andriani et al., 2024; Farobie et al., 2022). Despite this abundance, much of Indonesia's macroalgal biomass remains underutilized and is often limited in its commercial applications. Exploring applications of this readily available marine resource could not only enhance economic sustainability but also support the development of environmentally responsible biomaterials from local marine resources.

One promising use for macroalgal cellulose is in wound healing. Wound healing is a complex process that involves hemostasis, inflammation, proliferation, and tissue remodeling. An ideal wound dressing should provide a moist healing environment, have absorptive capacity, support cell proliferation, and protect against contamination (Nuutila & Eriksson). Cellulose-based biomaterials are suited for these functions due to their tensile strength, crystallinity, and mechanical rigidity. In addition, its hydrophilic nature facilitates moisture retention while promoting cellular adhesion and proliferation. Recent studies also suggest that macroalgae-derived cellulose may possess antibacterial properties, further enhancing its potential for wound treatment (El-Sheekh et al., 2023; Silva et al., 2020; Vasilakis et al., 2025). However, despite these advantages, research investigating the biomedical potential of macroalgal cellulose, particularly from species abundant in Indonesia, remains limited.

Therefore, this study aims to explore Indonesian macroalgae as a sustainable source of cellulose to develop a novel wound dressing. By evaluating the biological performance and wound healing potential of cellulose derived from locally available macroalgae, this research seeks to contribute to the advancement of sustainable biomedical materials while expanding the application of Indonesia's marine resources.

1.2 Objective

This study aims to evaluate the biological properties of biomembranes synthesized from Indonesian marine macroalgae through three main objectives:

1. To determine the antibacterial potential of the synthesized biomembranes against selected bacterial species.
2. To examine the cytotoxicity of the biomembranes on human skin keratinocytes (HaCaT cells) to ensure biocompatibility and safety for potential biomedical applications.
3. To investigate the wound-healing–related biological responses of the synthesized biomembranes on HaCaT cells by assessing gelatinase (MMP-9 & MMP-2) enzymatic activity (via gelatin zymography) and TGF-β1 gene expression (via qRT-PCR), as indicators of compatibility with wound repair processes.

1.3 Hypothesis

It is hypothesized that biomembranes synthesized from Indonesian marine macroalgae possess potential as wound dressing materials due to their cytocompatibility and compatibility with normal wound-healing processes. Specifically, these biomembranes are expected to be non-cytotoxic toward human skin keratinocytes (HaCaT cells) and not interfere with wound-healing–related cellular responses, as assessed by MMP-9 & MMP-2 enzymatic activity and TGF-β1 gene expression in treated cells. Furthermore, as the membrane preparation process may preserve residual bioactive compounds from the macroalgae, the biomembranes may exhibit additional antibacterial activity against common skin pathogens, including S*taphylococcus aureus, Pseudomonas aeruginosa, and Escherichia coli*.