Chapter 1

Introduction

1.1 Background

Throughout the centuries, crackers have been widely consumed due to their availability and long shelf life. Generally, crackers are marketed as having a thin, dry, and crispy texture, produced from a mixture of wheat flour, fat, salt, and water (Batista et al., 2019; Ozgoren et al., 2019). According to data from 6Wresearch (2025), the sales and consumption of the Indonesian crackers market are expected to grow at a significant compound annual growth rate (CAGR) of 8% between 2025 and 2031. However, the most recent reported data showed a growth rate in cracker consumption, indicating an approximately 60% shift in consumer preferences toward gluten-free snack products (Innovation, Trends, and Challenges in the Snack Industry, 2025). This progressive demand and preference among consumers are heavily influenced not only by individuals with gluten-related conditions but also by other health-conscious consumers who associate the consumption of gluten-free options with a healthier lifestyle (Hassan et al., 2024).

Despite the high demand for healthier snack products, the production of gluten-free crackers still faces significant challenges in manufacturing processes, recipe development for higher antioxidant content, and overall product quality (Massironi et al., 2024). Compared with other known functional ingredients, microalgae have attracted considerable attention in the food product development industry over the past few years. This incorporation of microalgae into food products offers a promising approach to enhancing their functional properties in the eyes of consumers (Wang et al., 2022). The growing interest in microalgae is evident in the rising market popularity of algae-based ingredients, as reflected in the global algae-based ingredients market, which is projected to grow at a CAGR of 7.7% in the coming years (Algae-Based Ingredients Market Outlook, 2025). This progressive demand is largely driven by their properties of providing a rich composition of bioactive compounds,

including natural pigments, vitamins, minerals, and polyunsaturated fatty acids (Oliveira & Bragotto, 2022). Additionally, microalgae also serve as an abundant source of natural antioxidants and offer a variety of other potential health benefits (Delikanli-Kiyak & Ozcan, 2026; Singh et al., 2025). This beneficial property of microalgae has led to the widespread industrial incorporation of several types of microalgae, such as *Spirulina* (*Arthrospira platensis*), *Chlorella vulgaris*, *Dunaliella salina*, and *Haematococcus lacustris,* into food products (Sathasivam et al., 2019).

Among the variety of microalgae types, the presence of *Chlorella vulgaris* (*C. vulgaris*) has become one of the widely recognized microalgae species as a suitable food ingredient and is already categorized as generally recognized as safe (GRAS) by the U.S. Food and Drug Administration (FDA) (Takyar et al., 2019). In recent years, this microalgae has gained significant attention as one of the functional ingredients that contain high bioactive compounds, such as omega- 3 polyunsaturated fatty acids, vitamin B12, and β-glucans (Zheng et al., 2024). Furthermore, it naturally contains chlorophyll and carotenoids, such as lutein and zeaxanthin, which exhibit strong antioxidant activity and the ability to reduce oxidative stress (Wang et al., 2024). As a result of these bioactive components, *C. vulgaris* has been associated with various pharmacological properties, such as immunomodulatory, antioxidant, antidiabetic, antihypertensive, antihyperlipidemic effects, and detoxification support, highlighting its potential applications in functional and health-oriented food products (Bito et al., 2020).

Therefore, the application of *Chlorella vulgaris* in gluten-free cracker formulations has attracted increasing research interest due to its potential to enhance antioxidant properties. This potential is attributed to its rich content of phenolic compounds, carotenoids, and chlorophylls, which are known to contribute to antioxidant activity (Cahyani & Isman, 2022; Massironi et al., 2024). However, its incorporation is typically limited to around 3% due to potential sensory changes such as strong green color, bitterness, and grassy off-flavors that may reduce consumer acceptance (Batista et al., 2019).

Although several studies have investigated the incorporation of *C. vulgaris* into food products, information regarding its application in gluten-free crackers remains limited. Furthermore, the effects of low-level *C. vulgaris* incorporation on antioxidant activity, sensory characteristics, and the stability of its bioactive compounds during baking have not been fully elucidated, highlighting the need for further investigation.

1.2 Objective

The objective of this study is to determine the effect of flour substitution with *Chlorella vulgaris* microalgae powder at varying concentrations on the physical properties, antioxidant activity, and sensory characteristics of gluten-free crackers.

1.3 Hypothesis

H0 (Null hypothesis): The flour substitution with *Chlorella vulgaris* microalgae powder at varying concentrations does not significantly affect the physical properties, antioxidant activity, and sensory characteristics of gluten-free crackers.

H1 (Alternative hypothesis): The flour substitution with *Chlorella vulgaris* microalgae powder at varying concentrations significantly affects the physical properties, antioxidant activity, and sensory characteristics of gluten-free crackers.