Chapter 1
Introduction

1.1 Background

The food industry faces several challenges in the coming years, including the need to feed a growing global population, meet the rising demand for personalized and healthy food options, and produce food in a way that is both affordable and environmentally sustainable (Tyupova & Harasym, 2024). Additionally, according to the United Nations, 13% of food is lost between harvest and sale (United Nations, 2023). This generally includes large by-products, such as peels, which may account for about 50% of the weight of fresh fruit in fruit processing industries. These types of residues often contain both economic and environmental implications (Tejada-Ortigoza et al., 2017). As a result, some research has focused on finding alternative uses for such waste by extracting value-added functional ingredients, including dietary fiber (Khanpit et al., 2021).

Dietary fiber has been shown to have many health advantages, such as the prevention of cardiovascular diseases, constipation, irritable bowel syndrome, colon cancer, obesity, and diabetes (Ciudad-Mulero et al., 2019). Furthermore, with increasing consumer interest in distinctive dietary fiber ingredients, fruit processing by-products have become a focus of interest as a rich source of dietary fiber in the last decade (Wanlapa et al., 2015). In turn, proper utilization and valorization of food waste also resolve some of the environmental problems and act as a sustainable method for improved health, with the enriched food being rich in health-imparting substances (Bhardwaj et al., 2022). A few examples of food products containing high fiber content include fruit peel, rice bran, and hemp seed milk residue.

Although hemp seed residue waste information is limited, the U.S. grew around 751,000 pounds of hemp seed in 2023 (USDA, 2024). As a comparison, the approximate annual mango peel waste globally is 8.81 million tons, and rice bran waste is around 29.3 million tons (García-Mahecha et al., 2023; Sharif et al., 2014). Thailand, as a major producer of mangoes and rice, yields over 1.25 million tons of mangoes and a total of 27.2 million tons of paddy rice every year. A portion of up to 60% of mangoes become by-products like peels and seeds, which are generally wasted or used as animal feed (Chaiwan et al., 2024). Mango peel can, nevertheless, be recycled in food products like flour, jelly, and cookies (Marçal et al., 2021). Similarly, rice bran makes up about 8–10% of the rice grain and is a nutritionally valuable by-product that remains underutilized (Wisetkomolmat et al., 2022). Meanwhile, hemp is a rapidly developing, ecologically friendly crop with diverse applications, including food. Yet, its processing by-products, such as from hemp milk, remain relatively untapped sources of dietary fiber (Burton et al., 2024). In addition, the diverse fiber compositions native to these by-products, i.e., mango peel with 40% fiber (pectin, cellulose), rice bran with 41% fiber (lignin, cellulose), and hemp seed with 28% fiber (cellulose, hemicellulose), enable them to synergistically complement or distinctly change the food functionality and sensory characteristics when incorporated into products (Ajila & Prasada Rao, 2013; Sapwarobol et al., 2021; Rizzo et al., 2023).

Although it is possible to integrate these food processing industry by-products or waste into products, consumers' resistance to "foods made from waste" is still a problem. Food scientists research ways to overcome this that strike a balance between sustainability, resource use efficiency, and nutrition. Three-dimensional food printing is one option that provides novel ways of using these by-products (Jagadiswaran et al., 2021). In recent years, 3D food printing has been a groundbreaking technology in the food industry that has found a new means of revolutionizing the production of food. In the last decade, its applications have varied from the preparation of nutritionally customized foods to the dosing of nutraceutical substances (Liu et al., 2017). Some of them include a study by Kewuyemi et al. (2022) that developed 3D-printed whole-grain sourdough and malt biscuits. Another application of 3D printing was shown in a study by Jagadiswaran et al. (2021), where they used industrial waste such as grape pomace and broken wheat as a base for 3D-printed cookies.

Cookies are among the most popular bakery foods and are eaten on a large scale as an instant source of energy. According to Statista (2025), the global cookie industry was valued at approximately USD 39.6 billion in 2023. It is projected to grow at a compound annual rate of between 4.7% and 5.3% over the next few years, with the ability to grow up to as much as between USD 54.9 billion by 2030 and USD 72.3 billion by 2035. Despite this, traditional cookies are largely devoid of basic nutrients, specifically dietary fiber, and therefore not as aligned with the growing demand of functional and nutrient-enriched foods (Asadi et al., 2020). For baking industries, like the production of cookies, 3D printing has immense potential to create customized cookies with complex designs and textures, providing increased repeatability and precision in food production (Pulatsu et al., 2022). In cookie production, 3D printing can create cookies with complex and well-defined geometries that are difficult to produce with conventional methods, enhancing visual quality and control over texture. 3D printing also allows the incorporation of fiber-containing ingredients without losing printability or texture if dough composition and printing parameters are optimally balanced (Yazici et al., 2021). 3D food printing facilitates prototyping of food, digitization, and streamlining of manufacturing and supply chains. As an additive process, it complies with the zero-waste concept by maximizing the use of food processing waste products (Yoha & Moses, 2023). Its ability to create customized foods makes it a suitable solution in managing shifting consumer demands and sustainability goals (Molina-Montero et al., 2023).

1.2 Objective

This 3D-printed cookie made from a food waste study aims to:

1. Investigate the optimum formulation of conventionally molded cookies with different ratios of mango peels, rice bran, and hemp seed milk residue using mixture design based on their physicochemical properties.

2. Analyze and compare the physicochemical properties of conventionally molded cookies in comparison to 3D-printed cookies by evaluating hardness, fracturability, moisture content, color, physical characteristics, and dietary fiber content.
3. Investigate consumer perceptions, acceptance, and concerns regarding 3D food printing technology, providing insights into its potential market acceptance.

1.3 Hypothesis

- Study 1: Formulation of conventionally molded cookies using mixture design

1. Null Hypothesis (H_0): The variation in mango peels, rice bran, and hemp seed milk residue ratios does not influence the determination of the optimum formulations in the mixture design.
2. Alternative Hypothesis (H_1): The variation in mango peels, rice bran, and hemp seed milk residue ratios influences the determination of the optimum formulations in the mixture design.

- Study 2: Physicochemical properties of conventionally molded cookies in comparison to 3D-printed cookies

1. Null Hypothesis (H_0): There is no significant difference in the physical properties of conventionally molded cookies in comparison to 3D-printed cookies.
2. Alternative Hypothesis (H_1): 3D-printed cookies exhibit significantly different physical properties (e.g., hardness, moisture content, color, porosity) compared to conventionally molded cookies.

- Study 3: Consumer Acceptance of 3D-Printed Fiber Cookies Among Thailand University Students Using FTNS and the Hedonic Scale

1. Null Hypothesis (H_0): The 3D-printed cookies are not accepted by Khon Kaen University students, as measured by the Food Technology Neophobia Scale (FTNS) and the hedonic scale.
2. Alternative Hypothesis (H_1): The 3D-printed cookies are accepted by Khon Kaen University students, as measured by the FTNS and the hedonic scale, and their acceptance differs from conventional cookies.