

Literature Study of Tempe Bioactive Compounds as Functional Foods in Indonesia

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ABSTRACT

Tempe is a locally originated food from Indonesia, enriched with numerous bioactive compounds that confer significant health benefits. This review article aims to comprehensively describe the various types of bioactive compounds present in Tempe, elaborate on their functional food roles, and elucidate the ways these compounds contribute to improved health. The methodology employed for this study involved a thorough literature review spanning the years 2013 to 2023. The findings revealed that Tempe contains essential bioactive compounds such as isoflavones, saponins, and amino acids, all of which exhibit potent antioxidant, antihypertensive, and antidiabetic properties. Regular consumption of Tempe can play a crucial role in enhancing overall health and preventing various diseases. In conclusion, Tempe serves as an exemplary functional food option, offering immense health advantages to the Indonesian population. Its rich composition of bioactive compounds makes it a beneficial addition to the diet, promoting well-being and healthy living.

Keywords: Functional food, Tempe, bioactive compounds

1. INTRODUCTION

Defining functional foods as food groups containing active compounds with beneficial effects on health has helped to establish a clearer understanding [1]. Among the traditional soy-based foods originating from Indonesia, tempe stands out as a well-known and revered delicacy, even gaining popularity in foreign countries. Primarily crafted using Glycine max soybeans, tempe also includes variations using alternative ingredients like red beans (*Phaseolus vulgaris*) [2]. The fermentation process of tempe involves the pivotal role of *Rhizopus* spp., with *Rhizopus oryzae* and *Rhizopus oligosporus* being commonly utilized mold types [3]. Praised for its affordability, soybean-based tempe has garnered immense popularity in Indonesia, being a source of essential nutrients and bioactive compounds vital for digestive, respiratory, and circulatory processes [4]. Tempe qualifies as a functional food due to its potential in addressing health issues such as anemia and diabetes prevention [5].

Bioactive compounds, classified as secondary metabolite compounds found in plants, comprise non-nutritional components of food. In Tempe, the content

of these bioactive compounds, along with essential nutrients, plays a crucial role in various physiological processes, including respiration, digestion, and blood circulation [4]. The diverse array of bioactive compounds in tempe manifests in a plethora of beneficial roles, spanning from being anticancer, antioxidant, antibacterial, hypoallergenic, anti-infective, hepatoprotective, to anti-hemolytic. Notably, Tempe is enriched with short peptide compounds, free amino acids, and simpler carbohydrates, making it highly favorable for consumption [6]. Flavonoids, one of the essential bioactive compounds, are abundant in soy tempe, with 100 grams containing approximately 183.48 ± 3.91 mgQE. These compounds exhibit a range of beneficial properties, including anti-inflammatory, antioxidant, anti-mutagenic, and anti-carcinogenic effects. Among the flavonoids, the isoflavone compounds present in soybean seeds showcase biological activity similar to estrogen hormone [7], with concentrations ranging from 128 to 380 mg/100 grams in soybean seeds [8]. Divided into two forms, glycoside, and aglycone, soybean seeds contain 12 types of isoflavone compounds [9]. Notably, the isoflavone content can differ between raw soybean seeds and finished products due to processing methods [10]. The antioxidant activity of isoflavones

contributes to preventing various ailments, including osteoporosis, colon cancer, breast cancer, coronary heart disease, menopausal syndrome, and hypertension [9].

The focus of this research lies in the comprehensive exploration of bioactive compounds in Tempe, particularly in the Indonesian context. While previous studies have touched upon the health benefits of Tempe, our article goes further by providing an in-depth analysis of the diverse array of bioactive compounds present in Tempe, including flavonoids and isoflavones. This article will discuss the latest findings on bioactive compounds in Tempe, elucidate their biological activities, and highlight their crucial role as a functional food. A better understanding of these compounds is expected to provide a strong foundation for the development of Tempe-based functional foods that benefit the health of the Indonesian population. Furthermore, we aim to bridge the gap between scientific knowledge and practical applications by discussing the potential. This holistic approach sets this research apart and contributes to the novelty of this research. This study will pave the way for innovative food product development and contribute to disease prevention efforts and improved quality of life for the people of Indonesia.

2. THEORETICAL FRAMEWORK

2.1. Development of Functional Food Definition

Functional food in Indonesia was once defined by the Food and Drug Supervisory Agency (BPOM), as stated in BPOM Head Regulation No. HK 00.05.52.0685 in 2005. However, this regulation was later revised in 2011 and replaced with BPOM Head Regulation No. HK.03.1.23.11.11.09909 of 2011, concerning the Supervision of Claims on Food Labels and Advertisements. As a result, functional food in Indonesia currently lacks a formal and standardized definition. Such discrepancies in the definition of functional food have hindered the progress of technology, innovation, commercialization, and international trade in functional food products. The variations in regulations and definitions across different countries also pose constraints on the trade of functional food products [11].

Functional food refers to food that contains active compounds other than nutrients, which can have positive effects on human health. It is an integral part of daily consumption and is considered acceptable from a sensory perspective. The functionality of these foods is based on their nutritional and non-nutritional content. These substances can be naturally occurring compounds, fortified compounds, or compounds formed through chemical reactions and microbial activities during food processing. Various terms are used to refer to foods that offer health benefits, such as functional food, Pharma food, Vita food, Designer food, Aceutical food, Phytochemical, Nutraceutical, Real food, Health food, and Natural food [12]. Generally, functional foods not only provide essential nutrients beneficial to the body but also possess properties that aid in preventing and treating various diseases. The rising prevalence of diet-related diseases across different age groups has driven increased demand for functional foods [13].

2.2. Bioactive Compounds

Secondary metabolic processes give rise to various compounds, including bioactive compounds. Bioactive compounds are secondary metabolites that contribute to the body's physiological functions and offer benefits beyond the nutritional value contained in food. Before being absorbed and distributed to organs that require them, bioactive compounds are initially absorbed in the digestive tract and then transported through the blood circulation [14]. These compounds are not only found in plants but can also be sourced from animals [15]

Numerous studies have been conducted on bioactive compounds, aiming to improve human health through their use as supplements and medicines. Bioactive compounds demonstrate properties such as anticancer, antibacterial, anti-inflammatory, and antioxidant activities, which are beneficial for human health [16].

2.3. Tempe

Tempe is a traditional Indonesian processed food that enjoys high demand and global recognition [17]. The primary ingredient for making tempe is often Glycine mas soybeans, but red beans (*Phaseolus*

vulgaris) can also be used [2]. The tempe-making process involves fermentation with the assistance of *Rhizopus* spp [3]. The study of tempe molds was first conducted by a microbiologist from the Netherlands. By 1946, tempe had gained popularity in Europe, and by 1984, there were 18 Tempe companies in Europe, 53 in America, and 8 in Japan [17].

The tempe-making process begins with washing the soybeans that will be used, followed by a 12-hour soaking period. This soaking softens the soybeans and aids in the cooking process. After soaking overnight, the soybeans are boiled in water for 30 minutes. Then, the soybeans are peeled to allow the microbes to penetrate them. Cooking continues for another 30 minutes until the soybeans become pale and tender in texture. The drained soybeans are then evenly distributed with tempe starter culture when cooled. Subsequently, the soybeans are wrapped in plastic and banana leaves. Fermentation takes place in a slightly dark, moderately ventilated, and adequately humid environment. The fermentation process typically lasts 30-40 hours after packaging [17].

Tempe is highly favored in the community due to its relatively affordable price. However, despite its popularity, many people are unaware of its health benefits. Tempe is a good source of iron, phosphorus, vitamin C, vitamin B, and antioxidants. Some of the health benefits of consuming tempe include its antioxidant content, which helps prevent premature aging and cancer cells, its unsaturated fatty acids, which contribute to heart health, and its anti-bacterial compounds produced by Tempe mold (*Rhizopus Oligosporus*), which aid in preventing infections. Additionally, Tempe can help prevent osteoporosis and anemia, and can be beneficial in treating diarrhea due to its easily digestible protein content [17].

2.4. Tempe's Potential as Functional Food in Indonesia

Food plays a crucial role in human health, as it provides essential nutrients and contributes to overall well-being. Additionally, the taste and quality of natural ingredients are important factors in determining food quality. In the current context, functional food is no longer merely consumed to meet daily nutritional needs but can also be developed as an alternative for

treating certain diseases. Functional food should be consumed like regular food or beverages, appealing to the general public in terms of shape, taste, color, and texture. Furthermore, functional food must have no side effects or adverse consequences on nutrient metabolism when consumed [18].

Tempe is highly sought after by the public due to its relatively low cost and rich vegetable protein content. The fermentation process of tempe with the fungus *Rhizopus oligosporus* is known to preserve and enhance its nutrients, resulting in a soft texture that is easily digestible. Soy-based tempe, with its appealing texture and color, is more commonly consumed [5]. Tempe exhibits great potential as a functional food in Indonesia, particularly due to its various advantages over raw soybeans resulting from the fermentation process. During the tempe fermentation process, the mold produces digestive enzymes that positively impact its nutritional value. Notably, the protease enzyme in Tempe can break down proteins [18].

Research by [20] highlights that tempe, as a locally based functional food, can contribute to enhancing the immune system and providing essential nutrients. The presence of active substances and beneficial nutrients makes Tempe a significant functional food worthy of consideration. As a locally based food, tempe holds the potential to provide considerable nutritional value to the community. Especially during the Covid-19 pandemic, tempe emerges as a locally based functional food that offers immense benefits for boosting and maintaining the body's immunity.

Despite the many advantages of tempe, its per capita consumption in Indonesia remains relatively low. The primary reason for this low consumption can be attributed to the lack of knowledge among many people about the nutritional content and active compounds that contribute to its health benefits. In contrast, other countries have experienced an increase in Tempe consumption, which can be attributed to the growing awareness of healthy lifestyles and the rising number of individuals adopting vegetarian diets [19]. Therefore, it becomes essential to enhance the Indonesian population's understanding of the health advantages of consuming tempe, considering that tempe is a local food originating from Indonesia.

3. METHOD

The method used in this study was a literature review. The references cited in this study consisted of previous research conducted from 2013 to 2023. Google Scholar, Mendeley, and Scopus were used to collect articles on bioactive compounds in tempe as a functional food in Indonesia. In conducting this literature review, a set of keywords and search terms have been employed to identify relevant sources. Some of the keywords and phrases used included "bioactive compounds in Tempe," "functional foods in Indonesia," "health benefits of tempe," "tempe and bioactive compounds," and related terms. References that provided substantial insights into the bioactive compounds present in Tempe and their potential health benefits have been included. The exclusion criteria involved excluding sources that did not directly contribute to the understanding of the topic or were not published within the specified timeframe.

4. RESULTS AND DISCUSSION

4.1. Bioactive Compounds in Tempe

Several studies have explored the potential health benefits of tempe, a fermented soybean product.

4.1.1. Bioactive Peptides

Bioactive peptide compounds are protein-derived molecules with various biological activities or short chains of amino acids, which are the building blocks of proteins. The previous research has reported Peptides Val-His and Ala-Leu-Glu-Pro that were found in tempe from several fermentation producers [20]. The other research conducted by Sabrina et al. (2022) reported that Six bioactive peptides (BPs) from CEST flour were successfully identified: Val-Glu-Glu (VEE, EBP1), Trp-Met-Phe-Asp-Trp (WMFDW, EBP2), Asp-Ala-Gly-Pro-Tyr-Gly-Pro-Ile (DAGPYGPI, BP3), Trp-Met-Gly-Pro-Tyr (WMGPY, BP4), Glu-Arg-Gly-Pro-Leu-Gly-Pro-His (ERGPLGPH, BP5) and Glu-Met-Gly-Pro-Ala (EMGPA, BP6). These bioactive peptide compounds are derived from proteins and have been found to possess various biological activities, such as anti-hypertensive, antioxidant, antithrombotic, antiandrogenic, anti-inflammatory, antimicrobial, and immunomodulatory effects [21,22].

The production of clean and safe tempe is claimed to yield many beneficial bioactive peptides that contribute to health, including anti-hypertensive, anti-diabetic, and antioxidant properties [23].

4.1.2. Fatty Acids

Fats consist of components known as fatty acids. Fatty acids found in nature are divided into two types: saturated fatty acids and unsaturated fatty acids. There are several fatty acid compounds commonly found in Tempe, such as oleic acid which is a precursor in the production of most polyunsaturated fatty acids (PUFA) and is the most common fatty acid. Oleic acid is derived from the desaturation of stearic acid and is produced by plants, animals, and bacteria [24]. This compound has benefits for heart health and can help lower levels of bad cholesterol (LDL) in the blood.

Linoleic acid is a polyunsaturated fatty acid also present in Tempe. It is an essential fatty acid, meaning the human body cannot produce it on its own and must obtain it from food. Linoleic acid plays a crucial role in maintaining skin and nervous system health. Linoleic acid is a part of LDL particles that are easily oxidized. LDL particles are composed of linoleic acid, which is a polyunsaturated fatty acid. Linoleic acid's chemical structure includes a double bond located at C₉ and C₁₂ [25]. Linolenic acid is the precursor of omega-3 fatty acids required by the human body. Linolenic acid is further divided into EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid) [26].

Tempe also contains linolenic acid, which is a precursor to omega-3 fatty acids. Linolenic acid is essential for heart health, brain function, and the nervous system. Palmitic Acid: Palmitic acid is one of the saturated fatty acids found in Tempe. It plays a role in cellular function and body metabolism. Stearic Acid: Stearic acid is another saturated fatty acid present in Tempe. This compound also plays a role in cellular function and is one of the components of vegetable fats. [26].

4.1.3. Sterol

The sterol compound found in Tempe was beta-sitosterol. Beta-sitosterol is one of the types of sterols commonly found in high concentrations in soy-based products like Tempe. This sterol belongs to the group

of phytosterols and has several potential health benefits, including the ability to reduce cholesterol absorption in the human body. [27].

4.1.4. Dietary Fiber

In 2001, the Australia New Zealand Food Authority (ANZFA) defined dietary fiber as parts of plants that can be consumed, extracted, or similar carbohydrates that are not digested and absorbed by the human small intestine, generally undergoing fermentation, either completely or partially, in the human large intestine. Dietary fiber can be oligosaccharides, polysaccharides, and lignin [28].

Dietary fiber can be divided into crude fiber and dietary fiber. Crude fiber comes from vegetables and fruits, while dietary fiber comes from carbohydrate sources such as green beans, potatoes, rice, and cassava [29]. Based on solubility in water, dietary fiber is categorized into two types: soluble dietary fiber and insoluble dietary fiber. Soluble dietary fiber can dissolve in water and can easily pass through the small intestine and then be fermented by microflora in the large intestine, such as pectin, gum, β -glucan, and fructan-inulin. On the other hand, insoluble fiber is difficult to ferment by microflora in the large intestine, such as cellulose, hemicellulose, and lignin [30].

4.1.5. Isoflavones

Isoflavones are bioactive compounds belonging to the flavonoid group with biological activities similar to estrogen hormones [7]. Isoflavones are divided into two major groups: aglycone and glycoside. Isoflavones have beneficial activities in preventing osteoporosis, colon cancer, breast cancer, coronary heart disease, menopause syndrome, and hypertension [9].

4.2. Activity of Bioactive Compounds in Tempe

Bioactive compounds are secondary metabolites found in plants and are part of non-nutritive food components. Tempe is a source of essential nutrients as well as bioactive compounds [4]. Bioactive compounds in tempe have functions such as anti-cancer, antioxidant, antibacterial, anti-allergic, anti-infection, hepatoprotective, and anti-hemolytic properties [42]. Table 1 below shows several activities of bioactive compounds in Tempe that are beneficial for health.

Table 1. The activity of Bioactive Compounds in Tempe

Compound Types	Activity	Ref
Peptide	Antihypertensive Antidiabetic Antioxidant	[23]
Linoleic acid	Anti coronary heart	[8]
Linolenic acid	Anti coronary heart	[8]
Oleic acid	Antioxidant	[31]
Sterols	Anticholesterol	[32]
Food fiber	Anticholesterol Antidyslipidemia Antidiabetic	[33]
Isoflavones	Anti cancer Coronary anti-cardiac Antihypertensive	[9]

4.3. Role of Bioactive Compounds in Tempe as Functional Food

Secondary metabolites that play a role in the physiological functions of the body and can have positive impacts beyond the nutritional value of food are called bioactive compounds [21]. According to [16], bioactive compounds have important functions as anticancer, antibacterial, anti-inflammatory, and sources of antioxidants for human health. Some functions of bioactive compounds found in Tempe include:

4.3.1. Antihypertensive

High blood pressure or hypertension is a disorder of blood pressure that can occur due to several factors such as age, occupation, education, smoking habits, obesity, alcohol consumption, exercise, potassium, and sodium intake related to blood pressure. Gender is a factor unrelated to blood pressure. Individuals over 40 years old have an increasing risk of hypertension due to aging and aortic valve damage over time [34]. Hypertension is categorized when systolic pressure is >140 mmHg and diastolic pressure is >90 mmH [35].

Tempe is made by adding the *Rhizopus oligosporus* mold in the fermentation process. *Rhizopus oligosporus* mold in soybean fermentation helps to

break down complex compounds into simpler ones that are easier to digest. The fermentation process of tempe produces several bioactive compounds such as superoxide dismutase (SOD), aglycone isoflavones, and gamma-aminobutyric acid, which act as antihypertensive, antioxidant, and antimicrobial agents [36].

4.3.2. Antidiabetic

Diabetes mellitus is a chronic metabolic disorder that requires continuous blood sugar control to prevent complications and other disorders [37]. Diabetes mellitus can be controlled based on glycemic predictions focused on blood sugar measurements [36]. Bioactive peptides found in Tempe play an important role as antidiabetic agents [38].

4.3.3. Antioxidant

The body naturally defends itself against various diseases through the immune system. Endogenous antioxidants are among those that protect body cells from free radical attacks and repair damaged cells [39]. Free radicals increase when a person suffers from severe diseases, leading to oxidative stress. Therefore, external antioxidants (endogenous antioxidants) from food and medications are needed to counteract free radicals and reduce oxidative stress. Several bioactive compounds in tempe act as antioxidants, including superoxide dismutase (SOD), aglycone isoflavones, and gamma-aminobutyric acid [36].

4.3.4. Anticholesterol

High cholesterol levels in the blood can cause narrowing of blood vessels and eventually lead to organ damage. Free cholesterol from blood vessels is transported to the liver by High-density lipoprotein (HDL), leading to blood vessel dilation. When very low-density lipoprotein (VLDL) and Low-density lipoprotein (LDL) levels are high, blood vessels narrow. High blood cholesterol levels can also lead to other diseases such as hypertension [35]. Tempe made from soybeans has beneficial effects in reducing triglyceride levels, LDL cholesterol, and total cholesterol, and increasing HDL cholesterol [40]. Tempe contains unsaturated fatty acids that can reduce cholesterol levels and counteract the negative effects of

sterols in the body. Polyunsaturated fatty acids (PUFAs) are known to lower cholesterol levels and neutralize the adverse effects of sterols [36].

4.3.5. Anti-coronary Heart Disease

Compounds in tempe related to coronary heart disease are linoleic acid and linolenic acid. Linoleic acid is part of LDL particles and is easily oxidized [25], while linolenic acid is a precursor of omega-3 fatty acids [26]. Linoleic and linolenic acids in soybeans are unsaturated fatty acids that cannot be produced by the body and have beneficial effects in preventing coronary heart disease [8].

4.3.6. Anticancer

Isoflavones are bioactive compounds of the flavonoid group that have biological activities similar to estrogen hormones [7]. Isoflavones are known to have antioxidant activity that can prevent diseases such as colon cancer and breast cancer. Previous research suggested that insufficient isoflavone intake can increase the risk of breast cancer by up to 2.85 times compared to normal isoflavone intake [41].

4.3.7. Antidyslipidemia

Dyslipidemia can increase the risk of cardiovascular diseases [42]. Dyslipidemia can be caused by a high-cholesterol diet. One way to address dyslipidemia is to follow a high-fiber diet. Soybeans in Tempe are known to control lipid profile levels and have antidyslipidemic activities [31].

4.4. Compounds in Tempe as Anti-nutritional

While this article primarily focuses on the numerous benefits of tempe due to its nutritional content and bioactive compounds, it's crucial to acknowledge the presence of anti-nutritional factors in tempe and provide a more comprehensive perspective on this topic. Anti-nutritional factors are compounds naturally occurring in some foods that can interfere with nutrient absorption or utilization, potentially posing health risks when consumed in large quantities.

In the case of tempe, as with many other foods, there are indeed anti-nutritional factors to be aware of. Here are some common anti-nutritional factors found in tempe [43–46]:

- a. Phytates: Tempe, like other soy-based products, contains phytates, which can bind to minerals like calcium, iron, and zinc, reducing their absorption in the body. This can be of concern in diets where tempe is a primary source of these minerals.
- b. Oxalates: Oxalates, found in certain plants including soybeans, can form kidney stones in individuals with a predisposition to this condition.
- c. Tannins: While present in lower quantities in tempe compared to some other legumes, tannins can interfere with protein digestion and mineral absorption.
- d. Protease Inhibitors: Soybeans, the main ingredient in tempe, contain protease inhibitors that can interfere with protein digestion in the stomach.
- e. Saponins: Saponins, though usually at low levels in tempe, can have a negative impact on nutrient absorption in high concentrations.

It's important to note that the anti-nutritional factors in tempe can be reduced through the fermentation process. *Rhizopus* spp., the molds used in tempe fermentation, produce enzymes that break down some of these compounds, making the nutrients in tempe more bioavailable [44].

5. CONCLUSION

Based on the discussion above, it can be concluded that tempe is a functional food with numerous benefits due to its nutritional content and bioactive compounds. Tempe contains bioactive peptides, linoleic acid, linolenic acid, oleic acid, sterols, dietary fiber, and isoflavones as bioactive compounds. These compounds exhibit various bioactive activities, such as antihypertensive, antidiabetic, antioxidant, anticholesterol, anticoronary heart, anticancer, and antihyperlipidemic effects. Despite these health-promoting properties, many people are still unaware of the benefits of the bioactive compounds in Tempe. Therefore, it is essential to disseminate knowledge about the advantages of Tempe, with the aim of increasing its consumption among the public. By raising awareness about the potential health benefits of tempe, more individuals can

incorporate it into their diets and harness its functional properties for improved well-being. Additionally, anti-nutritional factors are also of greater concern when a substantial portion of one's diet relies heavily on tempe or similar foods. For most people consuming tempe in a balanced diet, the potential negative effects of these compounds are minimal. To mitigate the impact of anti-nutritional factors, it's recommended to consume a varied diet that includes a range of nutrient sources and to cook tempe properly to further reduce their content.

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