



## A REVIEW OF NON-SOY TEMPEH AND POTENTIAL BENEFITS IN METABOLIC SYNDROME

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### ABSTRACT

*Metabolic syndrome is a medical condition that can occur due to various factors such as obesity, lack of physical activity, and genetic factors, and can lead to metabolic disorders. It can cause insulin resistance, high levels of triglycerides, low levels of high-density lipoprotein (HDL), high blood glucose levels, hypertension, and central obesity. One way to manage metabolic syndrome is through food interventions that have hypocholesterolemic effects, such as tempeh. This narrative review delves into the potential benefits of tempeh made from raw materials other than soybeans for metabolic syndrome disease. The review analyzed 13 original research articles published in the last sixteen years from Google Scholar, PubMed, and Science Direct. The findings suggest that tempeh made from non-soy ingredients like moringa seeds, quinoa seeds, barley seeds, fava beans, chickpeas, lotus seeds, and sorghum seeds contain bioactive components and nutritional content that can help reduce cholesterol levels, inflammation, oxidative stress, and blood pressure. Therefore, tempeh made from non-soy ingredients can be used as a functional food and nutraceutical to help improve the condition of metabolic syndrome. Further research on experimental animals is necessary to identify the effectiveness and mechanisms of non-soy tempeh at the molecular level against metabolic syndrome diseases.*

*Keywords: beans, fermented, metabolic syndrome, seeds, tempeh.*

## **ABSTRAK**

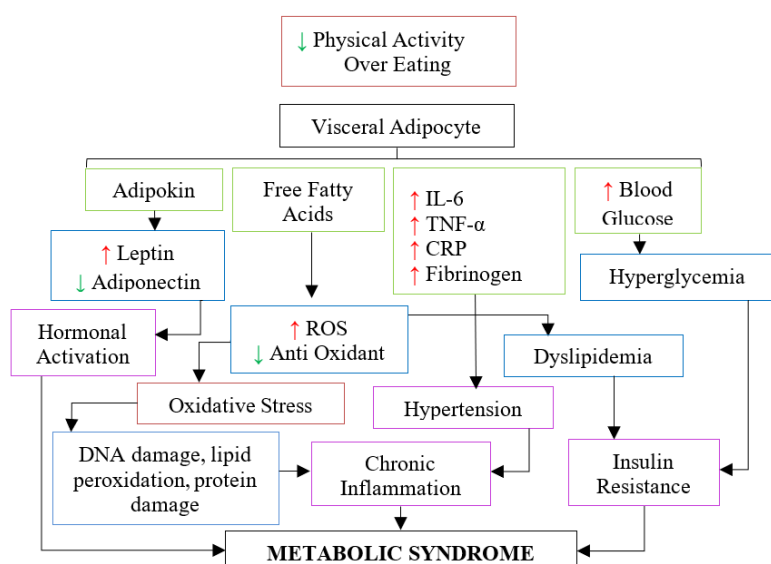
*Sindrom metabolik merupakan kondisi yang disebabkan karena kelebihan berat badan, obesitas, kurangnya aktivitas fisik, dan faktor genetik yang dapat menimbulkan adanya gangguan metabolik seperti resistensi insulin, tingginya kadar trigliserida dalam darah, kolesterol, rendahnya kadar high density lipoprotein (HDL), terjadinya obesitas sentral, tingginya kadar glukosa darah dan kejadian hipertensi. Penatalaksanaan sindrom metabolik dapat dilakukan dengan intervensi pemberian makanan dengan efek hipokolesterolemik yang salah satunya adalah tempe. Tinjauan naratif ini bertujuan untuk mendeskripsikan potensi manfaat tempe dengan bahan baku selain kedelai pada penyakit sindrom metabolik. Jurnal dalam enam belas tahun terakhir sebanyak 13 artikel penelitian asli dari Google Scholar, PubMed, Science Direct digunakan dalam naratif review. Hasil tinjauan diketahui bahwa tempe dengan bahan non-kedelai seperti biji kelor, biji quinoa, biji barley, kacang faba, kacang buncis, biji teratai, dan biji sorgum memiliki komponen bioaktif dan kandungan gizi dengan potensi manfaat terhadap penurunan kadar kolesterol, anti-inflamasi, mengurangi stres oksidatif, aktivitas antioksidan, menurunkan tekanan darah. Sehingga tempe dengan bahan non-kedelai dapat dimanfaatkan sebagai pangan fungsional dan nutasetikal dalam membantu memperbaiki kondisi sindrom metabolik. Penelitian lebih lanjut pada hewan coba diperlukan untuk mengidentifikasi efektivitas dan mekanisme tempe non-kedelai pada tingkat molekuler terhadap penyakit sindrom metabolik.*

*Kata kunci: kacang, fermentasi, sindrom metabolik, biji, tempe.*

## **INTRODUCTION**

Metabolic syndrome is a medical condition characterized by metabolic disorders like insulin resistance, high blood glucose levels, hypertension, central obesity, decreased levels of HDL cholesterol, and elevated blood triglyceride levels. If untreated, it can lead to cardiovascular disease and type 2 diabetes (Fahed et al., 2022). The prevalence of metabolic syndrome is 20-25%, with Europe at 15%, South Korea at 14.2%, America at 24%, and Indonesia at 23.34% (International Diabetes Federation (IDF), 2018).

Metabolic syndrome is a condition caused by multiple factors such as obesity, lack of physical activity, and genetics. It leads to insulin resistance, which can cause damage to insulin treatment. Insulin resistance can be caused by disrupted signaling pathways, damage to insulin receptors, and disruption of insulin secretion. If left untreated, it can cause damage to blood vessels and autonomic functions (Supreeya Swarup et al., 2022).



**Figure 1. Metabolic Syndrome Pathway**

Fat distribution in the body is a critical factor in metabolic syndrome. Upper body fat contributes significantly to insulin resistance. There are two types of fat accumulation: visceral and subcutaneous. Insulin resistance worsens due to fat accumulation in the liver and muscle tissue caused by high levels of non-esterified fatty acids in obesity, with visceral fat playing a more significant role than subcutaneous fat (Supreeya Swarup et al., 2022). Managing metabolic syndrome requires adopting a healthy diet and lifestyle while incorporating certain foods to reduce weight, cholesterol, blood pressure, and blood glucose levels. Tempeh is a particularly beneficial food for patients with metabolic syndrome due to its hypocholesterolemic effects, which can aid in reducing fat levels (Alrasyid, 2007).

Tempeh is a highly nutritious food made by fermenting soybeans with *Rhizopus* spp. It's popular in Indonesia and an excellent protein, vitamin B12, and bioactive compound source. According to Central Statistics Agency (BPS) data in 2022, the average weekly consumption per person is 0.140 kg (Badan Pusat Statistik (BPS), 2022).

Tempeh, a traditional Indonesian food, has become popular worldwide. It gained popularity in Europe after being introduced in the Netherlands in 1946. Tempeh was produced by 18 companies in Europe, 53 in America, and 8 in Japan in 1984. It has also become popular in countries such as China, Taiwan, India, Sri Lanka, Canada, Australia, and many Latin American and African countries (Sarwono, 2010).

Tempeh is a popular food product, especially in Indonesia, where it has been extensively studied by researchers from various countries. Experts from Japan, Germany, the United Kingdom, and the United States have analyzed tempeh's nutritional value, manufacturing process, and potential health benefits. This suggests that tempeh has a promising market demand and presents a great opportunity for entrepreneurs to establish a tempeh-making business (Sarwono, 2010).

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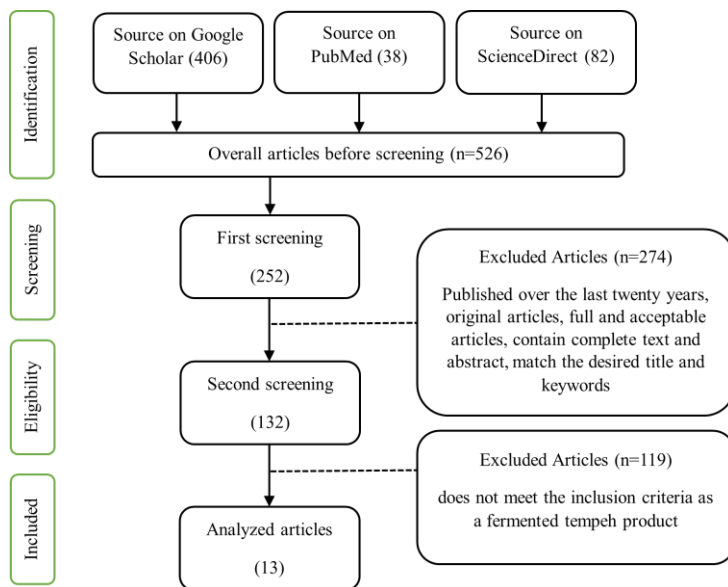
tempeh. This research highlights the potential market demand for tempeh and the opportunity for communities to start tempeh-making businesses (Ahnan-Winarno et al., 2021).

Tempeh is a highly nutritious food that can help manage metabolic syndrome. It contains beneficial nutrients like dietary fiber, B vitamins, iron, minerals, and antioxidants. Tempeh's isoflavones and polyunsaturated fatty acids help reduce cholesterol levels, making it an ideal food for patients with metabolic syndrome (Hassan et al., 2014). Tempeh production is no longer limited to soybeans. In Indonesia, other ingredients like tofu dregs, coconut milk meal, and velvet beans are used to make tempeh. This has led to new tempeh varieties (Vital et al., 2018). The use of nuts, seeds, and legumes in tempeh production began in 1963 and gained popularity after 2005 (Shurtleff & Aoyagi, 2020).

Several research studies have investigated the use of fermented products that are made from raw materials besides soybeans. Some of these raw materials include fava beans, chickpeas, quinoa seeds, barley seeds, sorghum seeds, lotus seeds, and moringa, which are fermented using *Rhizopus* spp. as the tempeh starter. These studies have shown that these fermented products contain higher levels of free amino acids, antioxidant activity, and protein absorption in comparison to those that are made using soybean raw materials. The purpose of writing the review of this article is to explore how tempeh can be developed from a base ingredient other than soy that is capable of enhancing its potential as a functional food and nutritional benefits in improving metabolic syndrome.

## **METHOD**

This article was written after a literature study to review several articles that develop or innovate tempeh products using non-soy basic ingredients with potential health benefits against metabolic syndrome disease. The study used a database of journal sources obtained through searches from Google Scholar, PubMed, and ScienceDirect. The inclusion criteria for the articles used as sources were that they should be original, contain complete text and abstracts, be written in English or Indonesian, have the desired title and keyword matches, and there should be no limit on the year of publication. On the other hand, articles on the topic of soybean tempeh and literature studies were excluded. The article search process is carried out by identifying articles with scope according to the subject of writing, then performing initial screening with adjustment of inclusion criteria, and subsequently performing screening to two with narrowing of scope adjusted to the title of the article, so that the final process of extracting the article produces 13 original articles dealing with non-soybean-based posts. The process of searching for articles can be seen in the PRISMA-LvR Research diagram image.



**Figure 2. PRISMA-LvR Research Diagram**

## RESULTS AND DISCUSSION

Tempeh is a soybean-based food product that undergoes a fermentation process with the addition of *Rhizopus* spp. This process can significantly increase the levels of vitamin B12, minerals, and antioxidants in tempeh compared to unfermented soybeans. *Rhizopus oligosporus*, a type of *Rhizopus* spp., produces phytase enzymes that break down phytate, a macro component in soybeans, into microcomponents. This helps the body digest and absorb tempeh's nutrients more easily (Radhitya Agus Budiono, 2016). The fermentation process produces nutrients such as genistein, daidzein (isoflavones), and  $\beta$ -sitosterol. These nutrients can help prevent cancer, cardiovascular disease, and type 2 diabetes mellitus, as well as regulate blood glucose levels (Huang et al., 2018).

Free fatty acids can be released from the tempe through the fermentation process, which also converts the isoflavone glycoside from soy to aglycon. It increases absorption and facilitates digestion. The fermentation process also improves the bioavailability of temperate iron. By inhibiting hepatic 3-hydroxy-3-methyl-glutaryl-coenzyme A (HMG-CoA) reductase, isoflavone-containing tempe and free fatty acids can help lower cholesterol levels (Hermosilla et al., 1993; Kuligowski et al., 2016). Another study suggests that tempe consumption can improve insulin response and decrease serum acyl-ghrelin by 30% (Cummings et al., 2001). Tempe is known to have the potential as a functional food and has the ability to control appetite, which helps people with metabolic syndrome.

Tempeh making involves several steps: soaking, peeling, washing, boiling, slicing, cooling, inoculating with a starter, and incubating at room temperature ( $30 \pm 2^\circ\text{C}$ ) (Rahayu et al., 2015). During soaking, bacteria growth occurs, resulting in the production of vitamin B12. Soaking also helps to improve the texture of soybeans, making it easier to exfoliate. Exfoliating removes the epidermis from soybeans, which is necessary for a perfect fermentation process using the tempeh starter. Boiling the soybeans is the next step to kill any unwanted microorganisms, remove anti-nutrients, and help in the protein denaturation process. The soybeans are boiled and then drained and cooled. After that, they are inoculated with a large container of *Rhizopus* spp., including *R. oligosporus*, *R. oryzae*, *R. chinensis*, and *R. arrhizus*. During the fermentation process, these

microorganisms break down lipids and proteins, which increases free fatty acids and amino acids, and decreases carbohydrate content. This process also improves the taste, bioavailability of minerals, antioxidant content, and isoflavones. Fermenting tempeh can effectively lower the levels of phytic acid and trypsin inhibitors (Abu-Salem et al., 2014).

The fermentation process using *Rhizopus oligosporus* can increase the concentration of phenolic acid compounds in soybeans, which can have higher bioactive activity than in whole soybeans (Do Prado et al., 2022). During the process of fermentation, the levels of free fatty acids, amino acids, and aglycone isoflavones in soybean substrates tend to increase. This happens due to the enzymatic activity of microorganisms such as lactic acid bacteria (BAL), yeasts, and molds. These microorganisms also produce bioactive peptides. The type of microorganism used affects the proteolytic, lipolytic, and glycolytic activities, as well as the bioconversion of fats, proteins, carbohydrates, and other components found in tempeh (Astawan et al., 2018).

**Table 1**  
**The Role of Fermentation in The Production of Bioactive Components in Non-Soy Tempeh**

No	Material	Bioactive Components and Nutritional Content	Microorganisms	Time (hour)	Impact	Reference
1	Moringa Seeds	amino acids, GABA, antioxidant activity, polyphenols	<i>R. oligosporus</i>	45	↑	(Aoki et al., 2023)
2	Fava Beans	GABA, $\gamma$ -linolenic acid, quercetin, kaempferol, amino acids, stigmaterol, phenolics antiradical activity, $\alpha$ -linolenic acid, linoleic acid	<i>R. oligosporus</i>	144	↑ ↓	(Polanowska et al., 2020)
3	Chickpeas	amino acids, fiber, leucine phytic acid, tannins, trypsin, lysin	<i>R. oligosporus</i>	48	↑ ↓	(Abu-Salem & Abou-Arab, 2011)
4	Quinoa Seeds	phenol, quercetin, thiamine, vitamins B1 and B2	<i>R. oligosporus</i>	40	↑	(Starzyńska-Janiszewska et al., 2016)
		Antioxidants, amino acids, histidine, chitosan		96	↑	(Starzyńska-Janiszewska et al., 2019a)
		phytic acid		96	↓	(Starzyńska-Janiszewska et al., 2023)
		phenolic compound, quercetin saponin		96	↑ ↓	(Starzyńska-Janiszewska et al., 2023)
5	Barley Seeds	protein, carbohydrates, fat, essential amino acids, fiber	<i>R. oligosporus</i>	30	↑	(Starzyńska-Janiszewska et al., 2017)
		iron, polyphenols, $\beta$ -glucan		28	↑ ↓	(Eklund-Jonsson et al., 2008; Sher et al., 2011)
		phytic acid		28	↓	(Eklund-Jonsson et al., 2008; Sher et al., 2011)
6	Sorghum Seeds	fiber, polyphenols	<i>R. oligosporus</i>	36	↑	(Bahlawan et al., 2022;
		tannin		42	↓	Devagopalan & Krishnaswamy, 2023)
7	Lotus Seeds	genistein, resistant starch	<i>R. oligosporus</i>	36	↑ ↓	(Ridhowati et al., 2023)
		phytic acid, tannins		36	↓	(Ridhowati et al., 2023)
		antioxidant activity, aglycones (genistein, daidzein)	<i>R. oligosporus</i>	36	↑	(Ridhowati et al., 2020)
		saponin			↓	

Tempeh is a well-known fermented soybean product, but there is another version of it that is made using alternative ingredients instead of soybeans. These ingredients include moringa seeds, fava beans, chickpeas, quinoa seeds, sorghum seeds, and lotus seeds. Recent research has shown that by using the fermentation process with *Rhizopus oligosporus*, the nutrient content and bioactive components of these non-soybean ingredients can be increased in tempeh products. This type of tempeh has the potential to be a functional food and offer nutraceutical benefits for people with metabolic syndrome disease.

### 1. Moringa Seeds Tempeh (*Moringa oleifera*)

Moringa tempeh is a type of food that undergoes a fermentation process. This process increases the food's antioxidant activity, GABA, free amino acids, and polyphenols. The protein found in Moringa seeds contains compounds with hydroxyl groups and proteolytic peptides. These compounds contribute to the increase in the food's beneficial properties. Additionally, the activity of protease enzymes produced by *Rhizopus oligosporus* during fermentation further increases the content of free amino acids in Moringa tempeh (Aoki et al., 2023).

Moringa plants, due to their low-fat content, can be used as a dietary supplement for obese individuals (Dhakad et al., 2019). Moringa seeds contain the enzymes quercetin and kaempferol which aid in the biosynthesis of vitamins and metabolites (Pasha et al., 2020). Moringa seeds have a high protein and fat content similar to soybeans, which can be used as an ingredient in making tempeh (Oyama et al., 2016; Shimada et al., 2011).

The Moringa plant contains  $\beta$ -sitosterol and 4-( $\alpha$ -L-Rhamnosyloxy)-benzyl glucosinolate, which helps reduce cholesterol levels, and quercetin-3-glycoside has anti-dyslipidemia and hypoglycemic properties (Jain et al., 2010). Moringa seed extract has anti-inflammatory benefits by reducing levels of TNF- $\alpha$ , IL-4, IL-6, and *myeloperoxidase* (Minaiyan et al., 2014). Moringa seed extract contains antioxidant compounds, such as glucomoringin, phenols, and flavonoids, that can reduce the occurrence of lipid peroxidation and immunoglobulin IgG, IgA, and antidiabetic activity in STZ-induced diabetic rats. This extract can help normalize diabetic rats in a healthy condition (Al-Malki & El Rabey, 2015).

### 2. Fava Beans Tempeh (*Vicia faba L.*)

Fava beans contain bioactive compounds such as phenolic compounds, dietary fiber, resistant starch, non-protein amino acids (GABA and L-DOPA), and bioactive peptides. They have potential as medicinal plants and biofunctional food ingredients (Martineau-Côté et al., 2022). Fermented fava bean seeds with *Rhizopus oligosporus*, used to make tempeh, resulted in a tenfold increase of free amino acids (Polanowska et al., 2020).

A study on tempeh made from fava beans discovered that the fermentation process by *Rhizopus oligosporus* caused a change in the total fatty acid content. The analysis results revealed that microorganisms play a role in reducing the amount of  $\alpha$ -linolenic acid and linoleic acid while increasing the level of  $\gamma$ -linolenic acid. This compound has been found to have significant health benefits, such as reducing inflammation and increasing the speed of nerve conduction in diabetic patients. It also helps to improve blood flow and reduce tingling in the extremities (Kapoor & Huang, 2006; Polanowska et al., 2020).

*Rhizopus oligosporus* in fava bean tempeh increases extracellular protease enzymes that play a role in the process of protein hydrolysis, the release of essential amino acids, and the increased content of quercetin and kaempferol. Tempeh fava beans show an increase in GABA content which is the result of glutamic acid through decarboxylase glutamate activity. GABA can control blood pressure and pulse rate, as well as reduce stress levels. Consumption of GABA-fortified products can lower blood pressure in suffering from hypertension (Gobbetti et al., 2010; Polanowska et al., 2020).

Fava bean peptides obtained from the hydrolysis of protein isolates can lower blood cholesterol by reducing the solubility of cholesterol in micelles and inhibiting the reductase of 3-hydroxy-3-methylglutaril coenzyme A (HMG-CoA), which is an important enzyme of the mevalonate pathway responsible for synthetic cholesterol (Ashraf et al., 2020).

**Table 2**  
**Bioactive Components of Non-Soy Tempeh on Potential Health Effects**

No	Non-Soy Tempeh	Bioactive Components and Potential Effects						
		antidiabetic	antioxidant	Anti-obesity	Anti-inflammatory	anti-atherogenic	anti-hypertension	oxidative stress
1	Moringa Seed Tempeh ( <i>Moringa oleifera</i> )	glucomoringin <sup>a</sup> , phenol <sup>a</sup> , flavonoids <sup>a</sup>	flavonoids <sup>b</sup> , polyphenolic <sup>b</sup>	$\beta$ -sitosterol <sup>c</sup> , quercetin <sup>c</sup>	Flavonoids <sup>b</sup> , polyphenolic <sup>b</sup>	Polyphenols <sup>d</sup>	GABA <sup>e</sup>	$\alpha$ -tocopherol <sup>b</sup>
2	Fava Bean Tempeh ( <i>Vicia faba L.</i> )	$\gamma$ -linolenic acid <sup>f</sup>	isoflavones <sup>g</sup>	pepsin <sup>h</sup> , trypsin <sup>h</sup>	$\gamma$ -linolenic acid <sup>f</sup>	quercetin <sup>i</sup> , kaempferol <sup>i</sup> , stigmaterol <sup>j</sup>	GABA <sup>ll</sup>	NA
3	Chickpea Tempeh ( <i>Cicer arietinum L.</i> )	phenolic <sup>k</sup> , Biochanin A <sup>l</sup>	Proteins <sup>m</sup> , Biochanin A <sup>l</sup>	phenolic <sup>k</sup> , $\alpha$ -amylase <sup>k</sup> , $\alpha$ -glucosidase <sup>k</sup> , resistant starch <sup>n</sup> , proteins <sup>m</sup>	Biochanin A <sup>l</sup>	NA	NA	Biochanin A <sup>l</sup>
4	Quinoa Bean Tempeh ( <i>Chenopodium quinoa</i> )	phenolic <sup>o</sup>	quercetin <sup>p</sup> , histidine <sup>q</sup> , itosan <sup>f</sup> , gluten free <sup>s</sup>	gluten free <sup>s</sup> , saponin <sup>t</sup> , histidine <sup>q</sup>	Thiamine <sup>u</sup>	NA	NA	NA
5	Barley Seed Tempeh ( <i>Hordeum vulgare</i> )	low glycemic index <sup>v</sup> , resistant starch <sup>w</sup>	polyphenols <sup>x</sup>	$\beta$ -glucan <sup>y</sup> , low fat <sup>z</sup> , resistant starch <sup>n</sup>	NA	polyphenols <sup>d</sup>	GABA <sup>e</sup>	NA
6	Sorghum Seed Tempeh ( <i>Sorghum bicolor</i> )	Polyphenols <sup>aa</sup>	Polyphenols <sup>aa</sup>	non-starch polysaccharides <sup>bb</sup> , high fiber <sup>cc</sup>	NA	hight fiber <sup>dd</sup>	NA	hight fiber <sup>ee</sup> , 3-deoxy anthocyanidin <sup>ff</sup>
7	Lotus Seed Tempeh ( <i>Nelumbo nucifera</i> )	neferine <sup>kk</sup>	genistein <sup>gg</sup> , starch <sup>hh</sup> , neferine <sup>ii</sup>	neferine <sup>jj</sup>	neferine <sup>ii</sup>	NA	genistein <sup>gg</sup>	NA

Note. a=(Al-Malki & El Rabey, 2015), b=(Mahajan et al., 2007), c=(Jain et al., 2010), d=(Andriantsitohaina et al., 2012), e=(Inoue et al., 2003; Kajimoto et al., 2004), f=(Kapoor & Huang, 2006; Polanowska et al., 2020), g=(Bennetau-Pelissero, 2017), h=(Ashraf et al., 2020), i=(Dabeek & Marra, 2019), j=(Batta et al., 2006), k=(Sánchez-Magaña et al., 2014), l=(Sadri et al., 2017), m=(Shi et al., 2019), n=(Higgins, 2014), o=(Aguilera et al., 2011), p=(Starzyńska-Janiszewska et al., 2023), q=(Starzyńska-Janiszewska et al., 2019b), r=(Froese & Ludlow, 2014), s=(Soares et al., 2013), t=(Yao et al., 2014), u=(Julianna L et al., 2024),v=(Jenkins et al., 2002), w=(Asare et al., 2011), x=(Arigò et al., 2018), y=(Aoe et al., 2017; Cosola et al., 2017; Gong et al., 2014; Velikonja et al., 2019), z=(Ashley et al., 2001), aa=(Chung et al., 2011), bb=(Warrand, 2006), cc=(Chen et al., 2018),dd=(Khoirun Nisa et al., 2021), ee=(Dykes, 2019; Ohira et al., 2017), ff=(Afify et al., 2012; Shen et al., 2018), gg=(Squadrito et al., 2013)(Zeng et al., 2017), ii=(Kim & Shin, 2023), jj=(Pan et al., 2009), kk=(Cevik et al., 2022), ll=(Gobbetti et al., 2010; Polanowska et al., 2020).

### 3. Chickpea Tempeh (*Cicer arietinum* L.)

The fermentation process applied to chickpea tempeh can increase its total phenolic content, which acts as an antioxidant. This increase can help inhibit  $\alpha$ -amylase and  $\alpha$ -glucosidase, which are enzymes that play a role in diabetes management. By providing natural inhibitors for these enzymes, bioprocessed chickpeas can help regulate post-prandial hyperglycemia. Therefore, chickpea tempeh can be considered a safer alternative for modulating carbohydrate digestion and controlling the glycemic index as a healthy food product (Sánchez-Magaña et al., 2014).

Tempeh made from chickpeas is an excellent source of protein, carbohydrates, and minerals. Compared to raw chickpeas, chickpea tempeh has less fat content, which decreases by 49.47%. This decrease in fat content occurs due to the fermentation process in chickpea tempeh with a dense substrate. The oxidation process and utilization of fatty acids by *Rhizopus oligosporus* as an energy source also contribute to the reduction in fat content (Abu-Salem & Abou-Arab, 2011).

The isoflavone biochanin A in chickpeas reduces oxidative stress by lowering MDA levels, increasing CAT and SOD levels, and improving the total antioxidant status in diabetic rats (Sadri et al., 2017). Chickpea proteins contain hydrolysates and peptides, which are the primary sources of bioactive peptides that exhibit antioxidant, hypolipidemic, and hypocholesterolemic activities (Shi et al., 2019).

Tempeh flour made with *Rhizopus oligosporus* resulted in increased gelatinization, amino acid content, protein digestibility, and resistant starch, as well as a lower water solubility index (Angulo-Bejarano et al., 2008). An increase in resistant starch occurs in chickpea tempeh flour due to the retrogradation of amylose. Resistant starch is a functional ingredient that has been known to improve health in various ways. One of its benefits is aiding in weight control, which can help prevent overweight and obesity (Higgins, 2014).

### 4. Quinoa Seeds Tempeh (*Chenopodium quinoa*)

Quinoa seeds are a great source of gluten-free protein which consists of amino acids, fiber, polyunsaturated fatty acids, and important vitamins (such as niacin, riboflavin, and  $\alpha$ -tocopherol) and minerals (calcium, iron, and magnesium). It is important to note that quinoa seeds have a higher content of phenolic compounds compared to other grains and cereals (Tang et al., 2015; Vega-Gálvez et al., 2010).

Tempeh products made from cereals are becoming increasingly popular due to the rise in demand for gluten-free foods. A gluten-free diet can help reduce fat accumulation, inflammation, and insulin resistance by regulating PPAR- $\alpha$ , LPL, HSL, and CPT-1 during lipolysis and fatty acid oxidation. This results in improved glucose homeostasis and increased expression of PPAR- $\gamma$ , which leads to an increase in adiponectin and GLUT-4 (Soares et al., 2013).

The fermentation process of tempeh quinoa with strains of *Rhizopus* spp. resulted in increased levels of quercetin derivatives, phenolic compounds, antioxidant potential, and decreased phytate concentrations (Starzyńska-Janiszewska et al., 2023). When beans are fermented to make tempeh quinoa, the resulting product has higher levels of carbohydrates, proteins, and essential amino acids, as well as a significant increase in dietary fiber (Starzyńska-Janiszewska et al., 2017).

Fermentation of tempeh quinoa seeds by *Rhizopus oligosporus* increases total phenols, antiradical activity, protein content, carbohydrate bioavailability, ash content, thiamine, and vitamins B1 and B2 twice as high as cooked seeds (Starzyńska-Janiszewska et al., 2016). The United States Food and Drug Administration (FDA) has approved thiamine as a treatment for cardiovascular disease caused

by thiamine deficiency. Thiamine pyrophosphate (TPP) is a form of thiamine that is metabolized through phosphorylation. TPP acts as an enzyme cofactor in the metabolism of glucose, lipids, and proteins (Julianna L. et al., 2024).

Histidine in tempeh quinoa acts as an antioxidant, and anti-inflammatory (Starzyńska-Janiszewska et al., 2019c). Fermented tempeh quinoa seeds have high levels of chitosan, which is a characteristic ingredient of *Rhizopus oligosporus*. Chitosan is known to have hypocholesterolemic activity and can lower fat levels. Chitin and chitosan make up 30% of the soluble fiber fraction in fermented quinoa seeds (Gharieb et al., 2015; Starzyńska-Janiszewska et al., 2019a)

## 5. Barley Seeds Tempeh (*Hordeum vulgare*)

Barley has anti-obesity components including  $\beta$ -glucan, resistant starch, polyphenols, and dietary fiber.  $\beta$ -glucan in barley can significantly reduce low-density lipoprotein, and total cholesterol, and prevent the accumulation of visceral fat in obese patients (Aoe et al., 2017; Cosola et al., 2017). Barley's  $\beta$ -glucan content improves glucose response and cholesterol levels in metabolic syndrome (Gong et al., 2014; Velikonja et al., 2019). Consuming barley can prevent insulin resistance, a risk factor for metabolic syndrome and diabetes mellitus, by increasing insulin sensitivity in impaired glucose metabolism (Bays et al., 2011; Choi et al., 2010).

Barley is the highest source of fiber ( $\beta$ -glucan) at 3.5-5.9% dry matter, which helps slow gastric emptying, delay glucose absorption, and improve postprandial glycemic response (Björklund et al., 2005). Barley contains a substance called  $\beta$ -glucan, which can help increase the feeling of fullness in the stomach by absorbing large amounts of water and forming a gel. This can help with weight loss. Eating three servings of whole grains daily can reduce lower body weight, reduce central adiposity, and reduce mass index (Jonnalagadda et al., 2011).

Tempeh barley's iron absorption increases with *Rhizopus oligosporus* fermentation due to reduced phytate content (Eklund-Jonsson et al., 2008). Barley tempeh has high nutritional value and bioavailable iron due to 28-hour fermentation with *Rhizopus oligosporus*, which also provides anti-fungal activity (Mei Feng et al., 2007). A recent study has demonstrated that *Rhizopus oligosporus* microorganisms secrete proteolytic enzymes during the fermentation process, which leads to an increase in the absorption of protein digestibility rates in barley tempeh. The proteolytic enzymes produced by *Rhizopus oligosporus* play a crucial role in breaking down proteins, thereby facilitating proteases to bind more protein in tempeh barley, resulting in a higher protein digestibility rate (Sher et al., 2011).

## 6. Sorghum Seeds Tempeh (*Sorghum bicolor*)

Sorghum seeds have a similar nutritional value and bioactive components to those found in corn, rice, and wheat. The main components of sorghum seeds include polysaccharides, proteins, and lipids. Sorghum, a type of cereal, has a lower digestibility of starch and protein as compared to other cereals. This is because tannins bond strongly with starch and sorghum protein. Starch is the primary source of calories in cereal grains and the human diet. Therefore, starch binding can help reduce caloric intake, which can be beneficial in fighting obesity. Additionally, slow digestion of starch can also aid people with diabetes by slowing down the release of blood glucose from starch-based foods after a meal (Girard & Awika, 2018).

Sorghum tempeh fermented at 35°C for 36 hours can be significant (Devagopalan & Krishnaswamy, 2023). Sorghum fermentation with *Rhizopus oligosporus* for 42 hours reduces tannin content through

a hydrolysis process that produces tannase enzymes. Tannase enzymes break down tannins into simpler compounds and release free phenolic compounds (Bahlawan et al., 2022; Osawa et al., 2000).

Tempeh sorghum was found to lower total cholesterol, LDL, and MDA levels in rats fed with an atherogenic diet. LDL and MDA levels have a positive correlation, so lowering LDL levels also decreases MDA levels (Khoirun Nisa et al., 2021). Tempeh and sorghum flour are both good sources of insoluble fiber, which can act as an antioxidant and reduce oxidative stress. In the large intestine, this fiber is digested by microbiota, producing SCFA. This, in turn, can decrease cholesterol synthesis in the liver by inhibiting the activity of HMG-CoA reductase, which decreases acetyl CoA. Additionally, the fiber can increase the activity of LDL receptors, which helps lower LDL levels (Chen et al., 2018; Dykes, 2019).

SCFA inflammation-induced oxidative stress in the gut can be corrected by suppressing immune cells and cytotoxic activity (Ohira et al., 2017). Food fermented by *Rhizopus oligosporus* has the potential to inhibit the increase in cholesterol levels through SCFA in experimental animals fed high-fat feed, making it a promising anti-hyperlipidemia agent (Dimidi et al., 2019; Huang et al., 2018). The phenolic compound 3-deoxyanthocyanidin found in sorghum has high antioxidant properties that can mitigate oxidative stress (Afify et al., 2012). Increasing antioxidant enzymes SOD and GSHPx can reduce oxidative stress by high antioxidant activity (Hasanuzzaman et al., 2020). Non-starch polysaccharides in sorghum seeds have the potential to improve intestinal function and lower cholesterol levels (Warrand, 2006).

## 7. Lotus Seeds Tempeh (*Nelumbo nucifera*)

Lotus products have medicinal properties due to phytochemicals. Lotus seeds are rich in amylose starch (40.20%) which regulates blood sugar solubility. Alkaloids and flavonoids in lotus seeds can affect hypoglycemia (Zeng et al., 2017). Lotus seed resistant starch supplementation prevents fatty liver in hyperlipidemic rats by increasing *norank\_f\_Muribaculaceae* growth and inhibiting *Allobaculum* proliferation, which improves cholesterol decomposition (Zeng et al., 2023). Neferin's anti-obesity properties help lower fasting blood glucose levels, insulin levels, TNF- $\alpha$ , and triglyceride levels, as well as improve insulin sensitivity in type 2 DM treatment (Pan et al., 2009). Treatment of diabetic rats with neferin resulted in significantly less reduction of blood glucose levels compared to untreated diabetic rats (Cevik et al., 2022). Lotus tempeh has low digestibility and is a healthier food product as it avoids blood sugar spikes. The digestibility increase is due to starch hydrolysis and phytate content decrease (Lin et al., 2009; Sahni et al., 2021).

Lotus tempeh has higher levels of genistein than soybean tempeh. Genistein has been found to improve various health markers in people with metabolic syndrome, such as increasing HDL-C and adiponectin, and lowering fasting glucose, insulin, cholesterol levels, and blood pressure (Ridhowati et al., 2020; Squadrito et al., 2013). Lotus tempeh has higher minerals, carbohydrates, fats, protein, and water. The nutritional content of tempeh is unaffected by steaming duration (Ridhowati et al., 2023). Lotus tempeh had more protein after 36 hours of fermentation than pea tempeh, but after 48 hours, pea tempeh had more protein (Sayed Rizwan et al., 2016). Fermentation improves tempeh quality by altering its chemical composition and reducing anti-nutrients such as phytic acid compounds and polyphenols (Murtini et al., 2011).

## LIMITATION OF THE STUDY

This article's limitation is that some of the studies we review have differences in data methodology and presentation, so our writing only depends on the quality and completeness of the study results. The recommendation for further research is that interventions on tempe products made from a variety

of base ingredients can be done on trial animals suffering from metabolic syndrome to know their health impacts.

## CONCLUSIONS AND SUGGESTIONS

Several research studies have shown that non-soybean foods such as quinoa seeds, barley seeds, fava beans, chickpeas, lotus seeds, moringa seeds, and sorghum seeds can be used to make tempeh. Fermentation with *Rhizopus* spp. has resulted in non-soybean tempeh that has a higher nutritional content and increased bioactive components compared to soybean tempeh. Non-soy tempeh has the potential to act as functional and nutraceutical food against metabolic syndrome disease, with anti-obesity, anti-inflammatory, anti-atherogenic, oxidative stress, antioxidant, and antihypertensive properties. However, further research is required to identify the effectiveness and mechanism of non-soy tempeh at the molecular level, and the appropriate dose of tempeh administration for patients with metabolic syndrome disease.

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