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TEMPOYAK: NUTRITIONAL COMPOSITION, PROBIOTIC POTENTIAL, AND HEALTH BENEFITS OF A TRADITIONAL FERMENTED DURIAN PRODUCT - A REVIEW

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ABSTRACT
Tempoyak is a traditional durian-based fermented product widely consumed in Indonesia and Malaysia. The spontaneous fermentation process is dominated by *Lactic Acid Bacteria* (LAB), mainly *Lactobacillus plantarum, Lactobacillus fermentum, and Pediococcus spp.,* which contribute to its flavor, aroma, and functional properties. While *tempoyak* has been consumed for generations, research on its nutritional composition, probiotic potential, and health benefits remains limited. This review summarizes *tempoyak*'s nutritional composition, bioactive compound content, and probiotic effects, particularly its impact on gut microbiota balance, glucose metabolism, inflammation reduction, and lipid metabolism. We found that *tempoyak* fermentation increases acidity, decreases sugar content, and enriches bioactive metabolites. *L. plantarum* and *P.acidilactici strains* in *tempoyak* exhibit high resistance to stomach acid and bile salts, strong adhesion to intestinal cells, and significant antioxidant and probiotic activities. These properties suggest *tempoyak* supports gastrointestinal health, regulates blood glucose, lowers cholesterol, and potentially protects against cardiovascular disease. *Tempoyak* shows promise as a fermented functional food for metabolic and cardiovascular health, though further research is needed to confirm its mechanisms and applications in disease prevention.

Keywords: cardiovascular disease; fermented durian, Lactic Acid Bacteria; metabolic health; *tempoyak*

INTRODUCTION

Tempoyak is a traditional durian-based fermented food popular among the Malay community in Indonesia and Malaysia. *Tempoyak* is made by adding salt to ripe or overripe durian, which is then naturally fermented for 3-7 days. Commonly used durian species include *Durio zibethinus* and *Durio kutejensis*, which have characteristics of sugar-rich pulp and soft texture that favor fermentation (Ardilla et al., 2022; Permatasari et al., 2022; Rahma et al., 2021). The fermentation process takes place spontaneously with the addition of 2-5% salt to inhibit the growth of pathogenic or spoilage microorganisms while encouraging the dominance of fermentative microflora, especially Lactic Acid Bacteria (LAB) such as *Lactobacillus plantarum*, *Lactobacillus fermentum*, and *Pediococcus spp* (Xiong et al., 2016). The microflora utilized the natural sugars of durian to produce lactic acid, which lowers the pH to around 3.5-4, creating a distinctive sour taste while serving as a preservative. *Lactobacillus plantarum* is crucial for flavor, food safety, and promoting gastrointestinal health and immunity.

In addition, fermentation produces changes in the texture of durian meat to become softer and creates a complex aroma typical of fermentation (Ahmad et al., 2018). This unique flavor and aroma is due to the presence of *volatile* compounds (alcohols, carboxylic acids, and esters, including 2,3-butanediol, 1,3-butanediol, octanoic acid, and propyl ester of acetic acid) (Belgis et al., 2016).

The fermentation process affects the *volatile* compounds in *tempoyak* so that they undergo significant changes compared to their fresh form, especially in components in the alcohol, carboxylic acid and ester groups (Xiao et al., 2023; Xiong et al., 2016; Zarezadeh et al., 2022; Zheng et al., 2021). In addition, the use of starter and non-starter in fermentation also affects the *volatile* components. The use of *Pediococcus acidilactici* as a starter in *tempoyak* fermentation was shown to reduce the amount of sulfur components, such as dimethyl disulfide and diethyl disulfide, and increase non-sulfur compounds, non-*volatile* acidity, and organic acid content such as lactic, malic, and acetic acids (Rahma et al., 2021; Sandesara et al., 2019; Şanlier et al., 2017). *Tempoyak* contains Lactobacillus strains producing exopolysaccharides (EPS), which serve as texturizing agents and potential probiotics. These Lactobacillus strains resist stomach acidity and bile salts, allowing survival in the digestive tract. They also exhibit antioxidant activity (32.29% to 73.36%), protecting the body from oxidative stress. Thus, *tempoyak* may be a valuable source of probiotics to enhance gut health and gastrointestinal microbiota balance, positioning it as both a traditional and functional food.

This review aims to summarize tempoyak's nutritional content, probiotic potential, and health advantages, highlighting its effects on gastrointestinal health, metabolic regulation, and cardiovascular wellness. A systematic search across several databases, including PubMed, Scopus, and Google Scholar, was performed to compile relevant studies published from 2000 to 2023. It features research that focuses on the biochemical, microbiological, and health-related characteristics of *tempoyak*, offering a thorough insight into its potential as a functional food.

While literature acknowledges *tempoyak*'s role in culinary traditions and mentions its microbiology, a comprehensive review of its nutritional composition, probiotic potential, and health benefits is lacking. Current studies have not fully clarified how *tempoyak* affects gut health, metabolism, and overall well-being. This review aims to fill this gap by analyzing *tempoyak*'s nutritional components and probiotic properties, including the exopolysaccharides produced during fermentation. We aim to compile existing knowledge and highlight tempoyak's potential health benefits, especially for gastrointestinal health, metabolic disease prevention, and as a source of natural antioxidants.

METHOD

This review used a systematic approach to synthesize information on the nutritional composition, probiotic potential, and health benefits of *tempoyak*, a fermented durian product. A comprehensive literature search was conducted in databases like PubMed, Scopus, and Web of Science. Studies were included if they: (1) focused on *tempoyak* from Durio species; (2) analyzed nutritional composition, including protein, fat, moisture, pH, and lactic acid; (3) characterized the Lactic Acid Bacteria (LAB) in *tempoyak*; (4) assessed the probiotic properties of LAB strains, such as acid and bile tolerance, adhesion to intestinal cells, and antioxidant activity; (5) investigated *volatile* compounds in *tempoyak* for flavor and aroma; and (6) examined potential health benefits concerning gastrointestinal health, metabolic diseases, and cardiovascular health. Studies were excluded if not in English or Bahasa Indonesian or if they lacked original data relevant to this review's scope.

A risk of bias assessment determines the methodological quality of included studies, evaluating factors like design, sample size, data collection, and analysis methods. Studies not meeting minimum quality standards were excluded, ensuring the review's findings are based on reliable, scientifically sound evidence. Data extraction was carried out on the chosen studies, summarizing key information about the durian species, fermentation techniques, nutritional makeup, LAB identification, probiotic characteristics, *volatile* compounds, and reported health benefits. The gathered data were synthesized and critically assessed to offer a thorough overview of the existing knowledge surrounding *tempoyak*'s potential as a functional food and its effects on human health.

RESULTS AND DISCUSSION

Nutritional Composition of *Tempoyak*

There were significant differences in the composition of *tempoyak* made from *Durio zibethinus* and *Durio kutejensis*, as well as fresh durian fruit (Fres Durio) from both species. These data include parameters such as protein, fat, moisture content, pH, TTA (Total Titratable Acidity), Lactic Acid Bacteria (LAB) count, reducing sugar, and lactic acid. *Tempoyak*, whether made from *Durio zibethinus* or *Durio kutejensis*, showed significant compositional changes compared to fresh durian. The moisture content of *tempoyak* (85.38% in *Durio zibethinus*) is much higher than that of fresh durian (60.77% in *Durio zibethinus* and 58.56% in *Durio kutejensis*). This is likely due to the addition of water or the breakdown of solid compounds during the fermentation process. In addition, *tempoyak* has a lower pH (4.1-4.2) than fresh durian (6.42), indicating increased acidity due to the production of organic acids such as lactic acid during fermentation. The protein content in *tempoyak* (2.84% in *Durio zibethinus*) is lower than fresh durian (3.67% in *Durio zibethinus* L. and 3.12% in *Durio kutejensis*).

This decrease may be due to protein degradation during fermentation. Meanwhile, the fat content in *tempoyak* (3.41% in *Durio zibethinus*) was relatively stable compared to fresh durian (3.38% in *Durio zibethinus* and 2.52% in *Durio kutejensis*). *Durio kutejensis* naturally has a lower fat content than *Durio zibethinus*. *Tempoyak* has a higher TTA (0.28% in *Durio zibethinus*) than fresh durian (0.09% in *Durio zibethinus* and 0.11% in *Durio* *kutejensis*). This indicates the accumulation of acid during fermentation. *Tempoyak* from *Durio kutejensis* also contained lactic acid of 2.169 g/100g, which was produced by the activity of Lactic Acid Bacteria (LAB). The amount of LAB in *Durio kutejensis tempoyak* (7.46 x 10^8 CFU/g) was much higher than *Durio zibethinus tempoyak* (9.8 x 10^7 CFU/g), indicating that fermentation in *Durio kutejensis* was more active. *Tempoyak* from *Durio kutejensis* had the highest reducing sugar content (39.21 g/100g), which may contribute to the sweeter flavor compared to *tempoyak* from *Durio zibethinus* L. or fresh durian. Fresh Durian *Durio zibethinus* had a reducing sugar content of 27.66 g/100g, while fresh *Durio kutejensis* had a lower reducing sugar content (16.38 g/100g). The increase in reducing sugars in *tempoyak* is likely due to the breakdown of complex carbohydrates during fermentation

Durio kutejensis has unique characteristics that set it apart from *Durio zibethinus* In addition to a lower fat content, *Durio kutejensis* also has a higher reduced sugar content in the form of *tempoyak*, which may make it preferable to those with a sweet tooth. The higher fermentation activity in *Durio kutejensis tempoyak* (indicated by higher LAB counts) also suggests the potential to produce more lactic acid and other flavor compounds.

Table 1. Nutritional composition of *tempoyak* and fresh durian

Composition	Types of *Tempoyak*		Fres Durio	
	Durio zibethinus	***Durio kutejensis***	***Durio zibethinus***	***Durio kutejensis***
Protein (%)	2.84	na	3.67	3.12
Fat (%	3.41	na	3.38	2.52
Water (%)	85.38	na	60.77	58.56
pH	4.1	4.2	6.42	6.42
TTA (Total Titratable Acidity) (%)	0.28	na	0.09	0.11
LAB Cfu/g	9.8 x 10^7	7.46 x 10^8	na	na
Reduced Sugar (%)	na	39.21	27.66	16.38
Lactic Acid (%)	na	2.169	na	na

Probiotic and Antioxidant Properties of *Tempoyak*

Tempoyak, as a fermented product from durian, has two important properties that provide health benefits, namely probiotic properties and antioxidant properties. The probiotic properties of *tempoyak* come from Lactic Acid Bacteria (LAB) such as *Lactobacillus plantarum* and *Lactobacillus curvatus*, which are known for their ability to ferment sugar into lactic acid, which contributes to digestive health and potentially boosts the immune system (Ahmad et al., 2018; Ardilla et al., 2022; E. S. Khalil et al., 2018). Data shows that *tempoyak* from *Durio kutejensis* contains 7.46 x 10^8 CFU/g, durian lai (*Durio zibethinus* x *Durio kutejensis*) and *tempoyak* from *Durio zibethinus* L. (9.8 x 10^7 CFU/g) (Ahmad et al., 2018; Marwati et al., 2024; Setyowati et al., 2013).

Lactic Acid Bacteria (LAB) strains isolated from *tempoyak* showed high resistance to acidic conditions and bile salts, indicating their ability to survive in the digestive tract environment. This resistance is an important characteristic for probiotic effectiveness, as it allows LAB to pass through the stomach and reach the intestines, where they can provide health benefits. In addition, LAB strains from *tempoyak* also showed strong adhesion to intestinal epithelial cells, which is a key factor in their colonization and continued presence in the gut microbiota. This adhesion ability helps LAB compete with pathogenic bacteria, strengthens the intestinal barrier, and contributes to immune system modulation. These findings confirm that *tempoyak* has potential as a fermented functional food, which contributes to the balance of gut microbiota, enhancement of immune response, and protection against gastrointestinal disorders (Ahmad et al., 2018; E. S. Khalil et al., 2018).

Additionally, probiotics, including those found in *tempoyak*, have been shown to have antioxidant properties, which help reduce oxidative stress by scavenging free radicals and enhancing the body's antioxidant defense system (Gerrans et al., 2025; Li & Zhang, 2019; Mishra et al., 2018; Xiao et al., 2023). Based on a study by Ahmad et al. (2018), *tempoyak* containing *Lactobacillus plantarum* showed antioxidant activity with a percentage inhibition against DPPH free radicals of 14.4%, which was lower than that of ascorbic acid (68.4%). In addition, the antioxidant capacity in the FRAP assay for L. plantarum cell-free supernatant was 41.08 µmol/ml, compared to ascorbic acid, which reached 76.12 µmol/ml.

The antioxidant effects of these probiotics are attributed to their ability to boost the antioxidant system and reduce free radical production, which plays a role in protecting cells from damage and supporting overall health. This mechanism involves an increase in endogenous antioxidant enzymes, such as *superoxide dismutase* (SOD), *catalase* (CAT), and *glutathione peroxidase* (GPx), which help neutralize free radicals and prevent oxidative stress. In addition, probiotics can also produce *antioxidant compounds*, such as *exopolysaccharides* (EPS) and bioactive peptides, which play a role in counteracting the damaging effects of Reactive Oxygen Species (ROS). Thus, consumption of probiotics, including those found in *tempoyak*, could potentially provide protection against various oxidative stress-related diseases, such as cardiovascular, neurodegenerative, and chronic inflammatory diseases (Gerrans et al., 2025; Li & Zhang, 2019; Mishra et al., 2018; Xiao et al., 2023).

***Volatile* Components**

The spontaneous fermentation process is carried out in the manufacture of *tempoyak*. Nonetheless, the main *volatile* constituents of fermented durian are still sulfur-containing *volatile*s. Besides the original flavor constituents, fermented durian produces five sulfur compounds and 16 non-sulfur compounds, while fresh durian loses the flavor of 11 sulfur components and 10 non-sulfur components when durian is fermented. Some alcohols, *carboxylic acids*, and *ester* components not found in fresh durian are present in fermented durian, such as 2,3-*butanediol*, 1,3-*butanediol*, *octanoic acid*, and *propyl ester* of *acetic acid*. Different proportions of *volatile* components and the presence or absence of sulfur and non-sulfur components determine the flavor properties of fermented durian. However, changes in the composition of *volatile* compounds in spontaneous fermentation can be controlled through the use of specific starters (Permatasari et al., 2022; Pirillo et al., 2021; Portincasa et al., 2022). One of the bacteria used as a starter in *tempoyak* fermentation is *Pediococcus acidilactici*, which contributes to a decrease in the amount of sulfur components as well as an increase in non-sulfur compounds and organic acids.

The use of *Pediococcus acidilactici* as a starter in *tempoyak* fermentation contributes to a decrease in the amount of sulfur components as well as an increase in non-sulfur compounds, non-*volatile* acidity, and organic acid content such as lactic, malic, and acetic acids (Ding et al., 2017). This decrease in sulfur compounds may reduce the pungent aroma typical of durian, while the increase in non-sulfur compounds may enrich the flavor profile and improve the stability of the fermented product. Although overall, there was no significant difference in sourness and aroma between *tempoyak* with and without starter, the sensory test results showed that *tempoyak* fermented with *P.acidilactici* was more acceptable to the panelists. This is likely due to a better balance of *volatile* compounds, resulting in a more harmonious aroma compared to spontaneous fermentation.

Analysis using Gas Chromatography-Mass Spectrometry (GC-MS) revealed that *tempoyak* treated with *P.acidilactici* UP02 contained 48 *volatile* compounds, with the main components being dimethyl disulfide and diethyl disulfide, which are typical compounds that contribute to the aroma of *tempoyak*. In addition, ethane,1-1-bis-ethylthio was also found, which is another sulfur compound that plays a role in the characteristic aroma of *tempoyak* (Kocsis et al., 2020; Kong et al., 2019; Kopin & Lowenstein, 2017; Permatasari et al., 2022; Pratiwi et al., 2021). These results suggest that the use of *P.acidilactici* starter not only helps control fermentation but can also improve the stability and sensory quality of *tempoyak*, making it more consistent in industrial-scale production and more acceptable to consumers.

Table 2. Amount of *Volatile* Compound of Fress Durio

No.	Group	Compound	*Durio kutejensis* (ng/g)	*Durio zibethinus* L (ng/g)
1	**Aldehydes**	*Acetaldehyde*	93.9	44.9
2	**Aldehydes**	*Hexanal*	30.5	62.2
3	**Aldehydes**	*Nonanal*	93.9	0.0
4	**Sulfur Compounds**	*Ethanethiol*	140.2	452.3
5	**Sulfur Compounds**	*Propanethiol*	59.2	86.4
6	**Sulfur Compounds**	*Methyl disulfide*	68.4	114.5
7	**Esters**	*Ethyl acetate*	381.9	1595.6
8	**Esters**	*Ethyl propanoate*	37.5	45.8
9	**Esters**	*Methyl-2-methylbutanoate*	81.4	249.0
10	**Alcohols**	*Ethanol*	290.4	1117.6

11	**Alcohols**	*2-Methyl-1-butanol*	192.7	688.8
12	**Alcohols**	*1-Pentanol*	11.4	146.0
14	**Ketones**	*3-Pentanone*	22.3	64.1
14	**Ketones**	*3-Hydroxy-2-butanone*	125.4	71.3
15	**Acids**	*Octanoic acid*	0.0	4.5

Health Benefits of *Tempoyak*

Tempoyak's effect on type 2 diabetes

Tempoyak, as a traditional durian-based fermented product, has the potential to help manage type 2 diabetes (T2DM) through various mechanisms involving probiotic activity, antioxidant effects, and regulation of glucose and lipid metabolism. The Lactic Acid Bacteria (LAB) content in *tempoyak*, such as *Lactobacillus plantarum* and *Pediococcus acidilactici*, plays a role in balancing the gut microbiota, which is known to be closely associated with insulin resistance and metabolic disorders (Chuah et al., 2016; Xiao et al., 2023; Xiong et al., 2016). These probiotic bacteria also contribute to increasing the production of Short Chain Fatty Acids (SCFAs), which can improve insulin sensitivity and reduce systemic inflammation that often occurs in people with type 2 diabetes (Portincasa et al., 2022; Zheng et al., 2021). In addition, *tempoyak* is rich in antioxidant and anti-inflammatory compounds, such as *polyphenols*, *flavonoids*, and exopolysaccharides (EPS), which play a role in reducing oxidative stress and protecting pancreatic β-cells from free radical damage (Anacleto et al., 2020).

The fermentation process also increases the content of organic acids such as lactic, acetic, and malic acids, which can help reduce postprandial blood glucose levels by slowing glucose uptake and improving insulin sensitivity (Chakraborty & Can, 2020) Furthermore, probiotics in *tempoyak* also have the potential to improve lipid metabolism, which plays a role in lowering cholesterol and triglyceride levels, thereby reducing the risk of cardiovascular complications often associated with type 2 diabetes (Chien et al., 2021; Hendijani & Akbari, 2018; Kocsis et al., 2020; Oh et al., 2020). Although various studies have indicated the benefits of probiotics and fermented foods in the management of diabetes, specific studies related to the effects of *tempoyak* on blood glucose control and insulin resistance are limited. Therefore, further research is needed to confirm the potential benefits of *tempoyak* as a functional food in supporting the management of type 2 diabetes.

Effects of *Tempoyak* on Cardiovascular Disease

One of the main factors in the development of cardiovascular disease is dyslipidemia, which is characterized by increased levels of LDL cholesterol and triglycerides and decreased HDL cholesterol (Kopin & Lowenstein, 2017; Pirillo et al., 2021). Probiotics present in *tempoyak*, especially *Lactobacillus plantarum* and *Pediococcus acidilactici*, are known to reduce blood cholesterol levels by several mechanisms, including increased bile acid excretion, decreased cholesterol synthesis in the liver, and modulation of gut microbiota involved in lipid metabolism. In addition, *tempoyak*'s antioxidant capacity derived from phenolic compounds, *flavonoids*, and exopolysaccharides (EPS) produced during fermentation plays a role in reducing oxidative stress, which is one of the main causes of atherosclerosis and vascular damage. Oxidative stress can trigger chronic inflammation that contributes to the development of hypertension, coronary heart disease, and stroke (N. Khalil et al., 2022; Stein et al., 2019; Zarezadeh et al., 2022; Ziaei et al., 2021).

The fermentation process of *tempoyak* also produces organic acids such as lactic, acetic, and malic acids, which are known to help stabilize blood pressure by improving endothelial function and improving blood vessel elasticity. Furthermore, probiotics in *tempoyak* have anti-inflammatory effects, which can reduce the production of *proinflammatory cytokines* such as TNF-α and IL-6, which play a role in chronic inflammation associated with cardiovascular disease (Ardilla et al., 2022; Chuah et al., 2016; Şanlier et al., 2017).

With better regulation of gut microbiota, the probiotics in *tempoyak* may also help reduce insulin resistance, which is often associated with an increased risk of metabolic syndrome and heart disease. Although various studies have shown that fermented foods and probiotics have a positive impact on heart health, specific studies on the effects of *tempoyak* on cardiovascular disease risk are limited. Therefore, further research is needed to explore the potential of *tempoyak* as a functional food in preventing and managing cardiovascular disease through more in-depth metabolic, inflammatory, and antioxidant mechanisms.

***Tempoyak*'s effect on obesity**

Tempoyak, as a durian-based fermented food, has the potential to provide benefits in the prevention and management of obesity through various mechanisms involving probiotic activity, regulation of fat metabolism, improved gut health, and anti-inflammatory and antioxidant effects. Obesity is often associated with gut microbiota imbalance, chronic inflammation, and impaired energy and lipid metabolism (Boulangé et al., 2016; Cheng et al., 2022; Gomes et al., 2018). Probiotics in *tempoyak*, such as *Lactobacillus plantarum* and *Pediococcus acidilactici*, may help balance the composition of the gut microbiota, which plays an important role in weight regulation and fat metabolism.

A healthy gut microbiota can increase the production of Short Chain Fatty Acids (SCFAs) such as butyrate, propionate, and acetate, which have positive effects on appetite regulation, energy metabolism, and insulin sensitivity. SCFAs also play a role in reducing fat accumulation in adipose tissue by increasing fat oxidation and inhibiting fat synthesis in the liver (Alard et al., 2016; da Silva et al., 2021; Kong et al., 2019). In addition, probiotics in *tempoyak* are also known to decrease fat absorption in the gut, which contributes to the reduction of body fat accumulation. In addition to the probiotic effect, *tempoyak* also contains antioxidant compounds such as *flavonoids* and *polyphenols* produced during fermentation.

These antioxidants help reduce oxidative stress and chronic inflammation, which are major factors in the development of obesity and its metabolic complications. Oxidative stress and chronic inflammation can cause metabolic dysfunction, increase insulin resistance, and accelerate fat accumulation in the body. By reducing oxidative stress, *tempoyak* consumption could potentially help improve insulin sensitivity and optimize energy metabolism, which is important in the management of obesity. Furthermore, *tempoyak* also contains organic acids, such as lactic and acetic acid, which play a role in suppressing appetite and improving fat metabolism. Some studies suggest that organic acids may regulate levels of hunger and satiety hormones, such as leptin and ghrelin, which play a role in the control of food intake (Kuhre et al., 2018; van den Broek et al., 2018). Although various mechanisms support the potential of *tempoyak* in managing obesity, direct clinical research on the effects of *tempoyak* on obesity is limited. Therefore, further research is needed to explore its benefits as a functional food that can aid in weight management as well as prevent complications of obesity.

Effects of *Tempoyak* on Blood Cholesterol

Tempoyak, as a durian-based fermented product, has the potential to lower blood cholesterol levels through mechanisms involving probiotic activity, lipid metabolism, and anti-inflammatory and antioxidant effects. High cholesterol, especially excessive Low-density Lipoprotein (LDL) levels, is a major risk factor for cardiovascular diseases such as atherosclerosis and hypertension (Gomez-Delgado et al., 2021; Sandesara et al., 2019). Studies show that the consumption of fermented foods containing Lactic Acid Bacteria (LAB) can help reduce total and LDL cholesterol levels and increase high-density lipoprotein (HDL), which is protective for heart health. Probiotics in *tempoyak*, such as *Lactobacillus plantarum* and *Pediococcus acidilactici*, play a role in reducing blood cholesterol levels through several mechanisms. One of them is cholesterol binding in the gut, where probiotics help prevent cholesterol absorption into the bloodstream by binding it and excreting it through the feces. In addition, LAB can also degrade bile acids in the gut, which forces the liver to use more cholesterol in the blood to synthesize new bile acids, thereby lowering total cholesterol levels (Ding et al., 2017; Jitpakdee et al., 2021; Liu et al., 2017; Qu et al., 2020).

In addition to probiotic effects, *tempoyak* also contains antioxidant compounds, such as *flavonoids* and *polyphenols*, which play a role in reducing oxidative stress that can lead to LDL oxidation, one of the main causes of atherosclerosis (Bertin et al., 2016; Dong et al., 2010). Fermentation also increases the production of organic acids, such as lactic and acetic acid, which are known to have effects in lowering cholesterol and triglyceride levels by improving lipid metabolism in the liver (Liu et al., 2017). Furthermore, consumption of *tempoyak* may also increase the activity of lipase enzymes, which help in the breakdown of fats and reduce the accumulation of lipids in the blood. Thus, *tempoyak* has the potential as a functional food to support cardiovascular health and lipid metabolism (Li & Zhang, 2019; Liang et al., 2024; Wang et al., 2020). Although various studies have shown the benefits of probiotics in lowering blood cholesterol levels, specific research on the effects of *tempoyak* on cholesterol is limited. Therefore, further research is needed to explore the effectiveness of *tempoyak* in the management of blood cholesterol levels and the prevention of cardiovascular disease.

CONCLUSIONS

Tempoyak, a fermented durian product, shows promise as a probiotic functional food with health benefits. Fermentation by Lactic Acid Bacteria (LAB) like *Lactobacillus plantarum* enhances its nutrients and probiotics. These compounds, including organic acids and *polyphenols*, support antioxidant, anti-inflammatory, and metabolic activities. Research indicates that *tempoyak* aids gut health, regulates blood sugar, lowers cholesterol, and supports cardiovascular health. LAB's resistance to stomach acid suggests *tempoyak*'s potential for improving gastrointestinal health and boosting immune responses. Its effects on lipid metabolism and oxidative stress make it a promising option for managing obesity and preventing chronic diseases.

Despite promising health benefits, there are key research gaps to address *Tempoyak*'s potential as a functional food. Future studies should conduct clinical trials to confirm tempoyak's effects on health outcomes in diverse populations, including those with metabolic syndrome or cardiovascular diseases. Investigating optimal fermentation conditions and specific starter cultures could improve tempoyak's consistency and properties. More research is also needed to understand the mechanisms behind its health benefits, particularly the role of bioactive compounds in metabolic regulation and disease prevention. Addressing these gaps can optimize *tempoyak*'s role as a functional food, benefiting public health and the food industry.

REFERENCES

Ahmad, A., Yap, W. B., Kofli, N. T., & Ghazali, A. R. (2018). Probiotic potentials of *Lactobacillus plantarum* isolated from fermented durian (*Tempoyak*), a Malaysian traditional condiment. *Food Science and Nutrition*, *6*(6). https://doi.org/10.1002/fsn3.672

Alard, J., Lehrter, V., Rhimi, M., Mangin, I., Peucelle, V., Abraham, A. L., Mariadassou, M., Maguin, E., Waligora-Dupriet, A. J., Pot, B., Wolowczuk, I., & Grangette, C. (2016). Beneficial metabolic effects of selected probiotics on diet-induced obesity and insulin resistance in mice are associated with improvement of dysbiotic gut microbiota. *Environmental Microbiology*, *18*(5). https://doi.org/10.1111/1462-2920.13181

Anacleto, S. L., Milenkovic, D., Kroon, P. A., Needs, P. W., Lajolo, F. M., & Hassimotto, N. M. A. (2020). Citrus flavanone metabolites protect pancreatic-β cells under oxidative stress induced by cholesterol. *Food and Function*, *11*(10). https://doi.org/10.1039/d0fo01839b

Ardilla, Y. A., Anggreini, K. W., & Rahmani, T. P. D. (2022). The role of indigenous Lactic Acid Bacteria Genus Lactobacillus in the fermentation process of Durian (*Durio zibethinus*) for *Tempoyak* production. *Berkala Ilmiah Biologi*, *13*(2), 42–52. https://doi.org/10.22146/bib.v13i2.4619

Belgis, M., Wijaya, C. H., Apriyantono, A., Kusbiantoro, B., & Yuliana, N. D. (2016). Physicochemical differences and sensory profiling of six lai (*Durio kutejensis*) and four durian (*Durio zibethinus*) cultivars indigenous Indonesia. *International Food Research Journal*, *23*(4).

Bertin, R., Chen, Z., Marin, R., Donati, M., Feltrinelli, A., Montopoli, M., Zambon, S., Manzato, E., & Froldi, G. (2016). Activity of myricetin and other plant-derived polyhydroxyl compounds in human LDL and human vascular endothelial cells against oxidative stress. *Biomedicine & Pharmacotherapy*, *82*, 472–478. https://doi.org/10.1016/j.biopha.2016.05.019

Boulangé, C. L., Neves, A. L., Chilloux, J., Nicholson, J. K., & Dumas, M. E. (2016). Impact of the gut microbiota on inflammation, obesity, and metabolic disease. In *Genome Medicine* (Vol. 8, Issue 1). https://doi.org/10.1186/s13073-016-0303-2

Chakraborty, A., & Can, A. S. (2020). *Calcium gluconate*.

Cheng, Z., Zhang, L., Yang, L., & Chu, H. (2022). The critical role of gut microbiota in obesity. In *Frontiers in Endocrinology* (Vol. 13). https://doi.org/10.3389/fendo.2022.1025706

Chien, S.-C., Chandramouli, C., Lo, C.-I., Lin, C.-F., Sung, K.-T., Huang, W.-H., Lai, Y.-H., Yun, C.-H., Su, C.-H., & Yeh, H.-I. (2021). Associations of obesity and malnutrition with cardiac remodeling and cardiovascular outcomes in Asian adults: A cohort study. *PLoS Medicine*, *18*(6), e1003661.

Chuah, L. O., Shamila-Syuhada, A. K., Liong, M. T., Rosma, A., Thong, K. L., & Rusul, G. (2016). Physio-chemical, microbiological properties of *tempoyak* and molecular characterisation of Lactic Acid Bacteria isolated from *tempoyak*. *Food Microbiology*, *58*. https://doi.org/10.1016/j.fm.2016.04.002

da Silva, T. F., Casarotti, S. N., de Oliveira, G. L. V., & Penna, A. L. B. (2021). The impact of probiotics, prebiotics, and synbiotics on the biochemical, clinical, and immunological markers, as well as on the gut microbiota of obese hosts. In *Critical Reviews in Food Science and Nutrition* (Vol. 61, Issue 2). https://doi.org/10.1080/10408398.2020.1733483

Ding, W., Shi, C., Chen, M., Zhou, J., Long, R., & Guo, X. (2017). Screening for Lactic Acid Bacteria in traditional fermented Tibetan yak milk and evaluating their probiotic and cholesterol-lowering potentials in rats fed a high-cholesterol diet. *Journal of Functional Foods*, *32*. https://doi.org/10.1016/j.jff.2017.03.021

Dong, Y., Zhang, M., Wang, S., Liang, B., Zhao, Z., Liu, C., Wu, M., Choi, H. C., Lyons, T. J., & Zou, M. H. (2010). Activation of AMP-activated protein kinase inhibits oxidized LDL-triggered endoplasmic reticulum stress in vivo. *Diabetes*, *59*(6). https://doi.org/10.2337/db09-1637

Gerrans, P., Hoffmann, A. O. I., McNair, S. J., & Pallant, J. I. (2025). More than objective knowledge: Exploring heterogeneity in individuals' response to a financial education initiative across multiple financial literacy domains. *Pacific Basin Finance Journal*, *90*. https://doi.org/10.1016/j.pacfin.2025.102669

Gomes, A. C., Hoffmann, C., & Mota, J. F. (2018). The human gut microbiota: Metabolism and perspective in obesity. In *Gut Microbes* (Vol. 9, Issue 4). https://doi.org/10.1080/19490976.2018.1465157

Gomez-Delgado, F., Katsiki, N., Lopez-Miranda, J., & Perez-Martinez, P. (2021). Dietary habits, lipoprotein metabolism and cardiovascular disease: From individual foods to dietary patterns. In *Critical Reviews in Food Science and Nutrition* (Vol. 61, Issue 10). https://doi.org/10.1080/10408398.2020.1764487

Hendijani, F., & Akbari, V. (2018). Probiotic supplementation for management of cardiovascular risk factors in adults with type II diabetes: A systematic review and meta-analysis. *Clinical Nutrition*, *37*(2). https://doi.org/10.1016/j.clnu.2017.02.015

Jitpakdee, J., Kantachote, D., Kanzaki, H., & Nitoda, T. (2021). Selected probiotic Lactic Acid Bacteria isolated from fermented foods for functional milk production: Lower cholesterol with more beneficial compounds. *LWT*, *135*. https://doi.org/10.1016/j.lwt.2020.110061

Khalil, E. S., Manap, M. Y. A., Mustafa, S., Alhelli, A. M., & Shokryazdan, P. (2018). Probiotic properties of exopolysaccharide-producing lactobacillus strains isolated from *tempoyak*. *Molecules*, *23*(2). https://doi.org/10.3390/molecules23020398

Khalil, N., Che Abdullah, S. N., Haron, S. N., & Hamid, M. Y. (2022). A review of green practices and initiatives from stakeholder's perspectives towards sustainable hotel operations and performance impact. *Journal of Facilities Management*. https://doi.org/10.1108/JFM-03-2022-0025

Kocsis, T., Molnár, B., Németh, D., Hegyi, P., Szakács, Z., Bálint, A., Garami, A., Soós, A., Márta, K., & Solymár, M. (2020). Probiotics have beneficial metabolic effects in patients with type 2 diabetes mellitus: a meta-analysis of randomized clinical trials. *Scientific Reports*, *10*(1). https://doi.org/10.1038/s41598-020-68440-1

Kong, C., Gao, R., Yan, X., Huang, L., & Qin, H. (2019). Probiotics improve gut microbiota dysbiosis in obese mice fed a high-fat or high-sucrose diet. *Nutrition*, *60*. https://doi.org/10.1016/j.nut.2018.10.002

Kopin, L., & Lowenstein, C. J. (2017). Dyslipidemia. *Annals of Internal Medicine*, *167*(11), ITC81–ITC96. https://doi.org/10.7326/AITC201712050

Kuhre, R. E., Wewer Albrechtsen, N. J., Larsen, O., Jepsen, S. L., Balk-Møller, E., Andersen, D. B., Deacon, C. F., Schoonjans, K., Reimann, F., Gribble, F. M., Albrechtsen, R., Hartmann, B., Rosenkilde, M. M., & Holst, J. J. (2018). Bile acids are important direct and indirect regulators of the secretion of appetite- and metabolism-regulating hormones from the gut and pancreas. *Molecular Metabolism*, *11*. https://doi.org/10.1016/j.molmet.2018.03.007

Li, F., & Zhang, H. (2019). Lysosomal Acid Lipase in Lipid Metabolism and beyond. *Arteriosclerosis, Thrombosis, and Vascular Biology*, *39*(5). https://doi.org/10.1161/ATVBAHA.119.312136

Liang, Z., Tang, Y., Yu, J., & Wang, Y. (2024). A collective incentive strategy to manage ridership rebound and consumer surplus in mass transit systems. *Transportation Research Part A: Policy and Practice*, *182*. https://doi.org/10.1016/j.tra.2024.104031

Liu, Y., Zhao, F., Liu, J., Wang, H., Han, X., Zhang, Y., & Yang, Z. (2017). Selection of Cholesterol-Lowering Lactic Acid Bacteria and its Effects on Rats Fed with High-Cholesterol Diet. *Current Microbiology*, *74*(5). https://doi.org/10.1007/s00284-017-1230-1

Marwati, Selviana Ave Maria Funan, Maulida Rachmawati, Aswita Emmawati, Miftakhur Rohmah, Agustu Sholeh Pujokaroni, Yudha Agus Prayitno, & Nurkaya, H. (2024). Sensory Response of Durian Lai *Tempoyak* and Its Potential as A Functional Food. *Buletin Loupe*, *20*(01), 1–6. https://doi.org/10.51967/buletinloupe.v20i01.2999

Mishra, A. K., Bairagi, S., Velasco, M. L., & Mohanty, S. (2018). Impact of access to capital and abiotic stress on production efficiency: Evidence from rice farming in Cambodia. *Land Use Policy*, *79*, 215–222. https://doi.org/10.1016/j.landusepol.2018.08.016

Oh, C.-M., Park, J. H., Chung, H. S., Yu, J. M., Chung, W., Kang, J. G., & Moon, S. (2020). Effect of body shape on the development of cardiovascular disease in individuals with metabolically healthy obesity. *Medicine*, *99*(38), e22036.

Permatasari, I., Turnip, M., & Kurniatuhadi, R. (2022). Isolasi dan karakterisasi bakteri asam laktat pada *tempoyak* durian pekawai (*Durio kutejensis* (Hassk.) Becc.). *Agroprimatech*, *6*(2), 7–16. https://doi.org/https://doi.org/10.34012/agroprimatech.v6i1.2987

Pirillo, A., Casula, M., Olmastroni, E., Norata, G. D., & Catapano, A. L. (2021). Global epidemiology of dyslipidaemias. In *Nature Reviews Cardiology* (Vol. 18, Issue 10). https://doi.org/10.1038/s41569-021-00541-4

Portincasa, P., Bonfrate, L., Vacca, M., De Angelis, M., Farella, I., Lanza, E., Khalil, M., Wang, D. Q. H., Sperandio, M., & Di Ciaula, A. (2022). Gut Microbiota and Short Chain Fatty Acids: Implications in Glucose Homeostasis. In *International Journal of Molecular Sciences* (Vol. 23, Issue 3). https://doi.org/10.3390/ijms23031105

Pratiwi, A. A., Syafnir, L., & Alhakimi, T. A. (2021). Penelusuran Pustaka Uji Aktivitas Ekstrak Kulit Buah Durian (*Durio zibethinus* murray) Sebagai Antibakteri Terhadap Bakteri Propionibacterium acnes dan Bakteri Staphylococcus epidermidis. *Prosiding Farmasi*, *7*(1).

Qu, T., Yang, L., Wang, Y., Jiang, B., Shen, M., & Ren, D. (2020). Reduction of serum cholesterol and its mechanism by: *Lactobacillus plantarum* H6 screened from local fermented food products. *Food and Function*, *11*(2). https://doi.org/10.1039/c9fo02478f

Rahma, A., Purwati, E., Juliyarsi, I., & Ferawati. (2021). Chemical properties of *tempoyak* from Lima Puluh Kota district of West Sumatera, Indonesia. *IOP Conference Series: Earth and Environmental Science*, *694*(1), 012069. https://doi.org/10.1088/1755-1315/694/1/012069

Sandesara, P. B., Virani, S. S., Fazio, S., & Shapiro, M. D. (2019). The forgotten lipids: Triglycerides, remnant cholesterol, and atherosclerotic cardiovascular disease risk. In *Endocrine Reviews* (Vol. 40, Issue 2). https://doi.org/10.1210/er.2018-00184

Şanlier, N., Başar, B., Aybüke, G. &, Sezgin, C., Nevin¸ Nevin¸sanlier, N., U¸srau¸sra Ba¸sar, B., G€, B., & Uke, A. (2017). Critical Reviews in Food Science and Nutrition Health benefits of fermented foods Health benefits of fermented foods. *Critical Reviews in Food Science and Nutrition*, *59*(3).

Setyowati, H., Hanifah, H. Z., & Nugraheni, R. P. (2013). KRIM KULIT BUAH DURIAN (*Durio zibethinus* L.) SEBAGAI OBAT HERBAL PENGOBATAN INFEKSI JAMUR Candida albicans. *Media Farmasi Indonesia*, *8*(2).

Stein, R., Ferrari, F., & Scolari, F. (2019). Genetics, Dyslipidemia, and Cardiovascular Disease: New Insights. In *Current Cardiology Reports* (Vol. 21, Issue 8). https://doi.org/10.1007/s11886-019-1161-5

van den Broek, M., de Heide, L. J. M., Emous, M., Wijma, R. B., Veeger, N. J. G. M., Wolthuis, A., Laskewitz, A. J., Heiner-Fokkema, M. R., Muller Kobold, A. C., Wolffenbuttel, B. H. R., & van Beek, A. P. (2018). Satiety and gastrointestinal hormones during a Mixed Meal Tolerance Test after gastric bypass surgery: association with plasma amino acid concentrations. *Surgery for Obesity and Related Diseases*, *14*(8). https://doi.org/10.1016/j.soard.2018.05.010

Wang, G., Si, Q., Yang, S., Jiao, T., Zhu, H., Tian, P., Wang, L., Li, X., Gong, L., Zhao, J., Zhang, H., & Chen, W. (2020). Lactic Acid Bacteria reduce diabetes symptoms in mice by alleviating gut microbiota dysbiosis and inflammation in different manners. *Food and Function*, *11*(7). https://doi.org/10.1039/c9fo02761k

Xiao, R., Wang, L., Tian, P., Jin, X., Zhao, J., Zhang, H., Wang, G., & Zhu, M. (2023). The Effect of Probiotic Supplementation on Glucolipid Metabolism in Patients with Type 2 Diabetes: A Systematic Review and Meta-Analysis. In *Nutrients* (Vol. 15, Issue 14). https://doi.org/10.3390/nu15143240

Xiong, T., Li, J., Liang, F., Wang, Y., Guan, Q., & Xie, M. (2016). Effects of salt concentration on Chinese sauerkraut fermentation. *LWT*, *69*. https://doi.org/10.1016/j.lwt.2015.12.057

Zarezadeh, M., Musazadeh, V., Faghfouri, A. H., Roshanravan, N., & Dehghan, P. (2022). Probiotics act as a potent intervention in improving lipid profile: An umbrella systematic review and meta-analysis. In *Critical Reviews in Food Science and Nutrition* (Vol. 63, Issue 2). https://doi.org/10.1080/10408398.2021.2004578

Zheng, F., Wang, Z., Stanton, C., Ross, R. P., Zhao, J., Zhang, H., Yang, B., & Chen, W. (2021). Lactobacillus rhamnosus FJSYC4-1 and Lactobacillus reuteri FGSZY33L6 alleviate metabolic syndrome via gut microbiota regulation. *Food and Function*, *12*(9). https://doi.org/10.1039/d0fo02879g

Ziaei, R., Ghavami, A., Khalesi, S., Ghiasvand, R., & Mokari_yamchi, A. (2021). The effect of probiotic fermented milk products on blood lipid concentrations: A systematic review and meta-analysis of randomized controlled trials. *Nutrition, Metabolism and Cardiovascular Diseases*, *31*(4). https://doi.org/10.1016/j.numecd.2020.12.023