



Research Article

Postprandial Glycaemic Response to a Tempeh-based Functional Food Among Non-diabetic, Diabetic, and Tuberculosis Patients with Diabetes in Indonesia

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Abstract

Tuberculosis (TB) and diabetes mellitus (DM) comorbidity presents a growing nutritional challenge, particularly in low- and middle-income countries. Adequate protein intake is essential for TB recovery, while postprandial glycaemic control remains critical for individuals with DM. Tempeh-based foods may serve as culturally acceptable functional foods with favourable metabolic effects. This study aimed to describe postprandial glycaemic response patterns following consumption of a tempeh-based functional food (ATemp) among non-diabetic, diabetic, and TB patients with diabetes. A quasi-experimental observational study was conducted in Bandung, Indonesia, involving 178 adults classified into non-diabetic (n=100), diabetic (n=50), and TB–DM (n=28) groups. Fasting blood glucose (FBG) and 2-hour postprandial glucose (2h-PPG) levels were measured after ATemp consumption. Glycaemic responses were analysed descriptively across groups. Mean fasting glucose levels were 83.7 ± 10.6 mg/dL in non-diabetic participants, 170.4 ± 67.6 mg/dL in diabetic participants, and 156.6 ± 75.2 mg/dL in TB–DM participants. Postprandial glucose levels demonstrated modest incremental changes across all groups. Despite elevated baseline glucose in diabetic and TB–DM participants, postprandial glycaemic excursions following ATemp consumption remained limited. Consumption of a tempeh-based functional food was associated with a favourable postprandial glycaemic response across different metabolic conditions. These findings support the potential role of tempeh-based functional foods in nutritional management strategies for diabetes and TB–DM comorbidity.

Keywords

Tempeh, Functional Food, Postprandial Glycaemia, Diabetes Mellitus, Tuberculosis-diabetes Comorbidity, Fermented Foods

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1. Introduction

Tuberculosis (TB) and diabetes mellitus (DM) are two major global health challenges that increasingly coexist, particularly in low- and middle-income countries (LMICs) [1-3]. TB remains one of the leading causes of death from infectious diseases worldwide, while the prevalence of DM continues to rise rapidly due to demographic transitions, urbanisation, and lifestyle changes [1, 3]. The convergence of these two conditions has created a growing public health concern, as diabetes is a well-established risk factor for the development of active TB, and TB infection itself can adversely affect glycaemic control [4-6]. This bidirectional relationship contributes to delayed sputum conversion, increased risk of relapse, higher mortality, and poorer treatment outcomes compared with TB or DM alone [2, 5].

Diabetes impairs both innate and adaptive immune responses, increasing susceptibility to *Mycobacterium tuberculosis* infection [4, 7]. Chronic hyperglycaemia alters macrophage and lymphocyte function, compromises cytokine signalling, and disrupts host defence mechanisms. Conversely, TB infection may exacerbate glucose dysregulation through chronic inflammation, stress-related hormonal changes, and altered energy metabolism [6, 8]. Inflammatory mediators associated with TB can promote insulin resistance, while anti-tuberculosis pharmacotherapy may further complicate metabolic control [6, 9]. Consequently, individuals with TB–DM comorbidity often experience unstable glycaemic profiles, posing significant challenges for integrated disease management.

Nutrition plays a central yet frequently underemphasised role in the management of both TB and DM [10, 11]. Adequate nutritional intake is essential for TB patients to prevent weight loss, preserve lean body mass, support immune recovery, and improve treatment adherence [10]. Protein requirements are often elevated due to increased catabolism and the need for tissue repair. In contrast, nutritional management of DM focuses on maintaining glycaemic stability, particularly by moderating carbohydrate intake and limiting excessive postprandial glucose excursions [12]. These differing nutritional priorities create a complex dilemma when TB and DM coexist, as dietary strategies aimed at increasing energy and protein intake may inadvertently compromise glycaemic control if not carefully designed.

In many LMIC settings, access to specialised medical nutrition therapy and diabetes-specific food products remains limited [11, 13]. Dietary practices are often shaped by cultural preferences, affordability, and food availability rather than clinical guidelines. As a result, there is a pressing need for practical and culturally acceptable dietary strategies that can simultaneously address the nutritional demands of TB and the metabolic constraints of DM. Within this context, functional foods derived from locally available ingredients represent a promising and potentially scalable approach [14].

Functional foods are defined as foods that provide health

benefits beyond basic nutrition by modulating physiological processes or reducing disease risk [14]. Recent research increasingly highlights postprandial metabolic responses as clinically meaningful outcomes, particularly in the context of chronic metabolic diseases [15, 16]. Postprandial glycaemic excursions contribute substantially to overall glycaemic burden, oxidative stress, and vascular complications in diabetes [16, 17]. Therefore, foods that elicit moderated postprandial glucose responses are of particular interest for both preventive and therapeutic nutrition strategies.

Fermented foods have attracted growing attention within functional food research due to their potential to improve nutrient bioavailability, alter carbohydrate digestibility, and generate bioactive compounds during fermentation [18, 19]. Fermentation can modify starch structure, reduce antinutritional factors, and enhance protein digestibility through enzymatic activity. These changes may influence the rate and extent of glucose absorption following consumption, thereby contributing to more favourable postprandial glycaemic profiles [19, 20]. Importantly, fermented foods are deeply embedded in traditional diets across many cultures, increasing their potential for long-term dietary adherence.

Tempeh is a traditional fermented soybean product widely consumed in Southeast Asia, particularly in Indonesia. Produced through solid-state fermentation using *Rhizopus* species, tempeh is recognised as a rich source of high-quality plant protein, dietary fibre, and micronutrients [21, 22]. The fermentation process leads to partial degradation of complex carbohydrates and proteins, resulting in improved digestibility and altered macronutrient composition. Several studies have demonstrated that fermentation increases resistant starch fractions and reduces rapidly digestible starch, factors associated with moderated postprandial glycaemic responses [20, 23].

Beyond its macronutrient profile, tempeh contains bioactive compounds, including isoflavone aglycones and fermentation-derived peptides, which have been reported to exert antioxidant, anti-inflammatory, and insulin-sensitising effects [24-26]. These properties are particularly relevant in populations experiencing chronic low-grade inflammation, such as individuals with DM or TB–DM comorbidity. Consequently, tempeh-based foods have gained increasing attention as functional foods capable of supporting metabolic health while providing adequate protein intake.

Previous studies have explored the glycaemic index or glycaemic response of tempeh and tempeh-derived products, primarily in healthy individuals or people with diabetes [23, 27, 28]. Overall, these studies suggest that tempeh-based foods elicit lower or more moderated postprandial glycaemic responses compared with non-fermented soybean products or refined carbohydrate foods. However, most existing evidence has been generated under controlled laboratory conditions or within single-disease populations, limiting its applicability to more complex clinical contexts.

Evidence regarding postprandial glycaemic effects of tempeh-based functional foods among individuals with TB–DM comorbidity remains scarce. This population represents a nutritionally and metabolically vulnerable group characterised by infection-related inflammation, increased energy expenditure, altered appetite, and medication-related metabolic effects [6, 9, 29]. Understanding how culturally relevant functional foods influence postprandial glycaemia in this context is essential for developing realistic and effective dietary strategies.

Therefore, the present study aimed to describe postprandial glycaemic response patterns following consumption of a tempeh-based functional food (ATemp) among non-diabetic, diabetic, and TB patients with diabetes in Bandung, Indonesia. By focusing on postprandial glucose changes in a community-based setting, this study seeks to contribute novel evidence supporting the use of culturally embedded functional foods in populations facing concurrent infectious and metabolic disease burdens.

2. Materials and Methods

2.1. Study Design and Setting

This study used a quasi-experimental observational design and was conducted as part of an applied nutrition research project in Bandung, Indonesia. The primary objective was to describe postprandial glycaemic response patterns following consumption of a tempeh-based functional food under real-world community conditions. A descriptive approach was selected to reflect practical dietary contexts rather than controlled laboratory-based glycaemic index testing.

Data collection was carried out in community and clinical settings associated with tuberculosis and diabetes management services. The study was conducted over several months to ensure adequate recruitment across predefined metabolic groups.

2.2. Study Participants

A total of 178 adult participants were recruited and categorized into three groups based on metabolic and clinical status:

- 1) Non-diabetic (non-DM)
- 2) Diabetic (DM)
- 3) Tuberculosis with diabetes (TB–DM)

With the eligibility criteria included as follow:

- 1) age ≥ 18 years;
- 2) willingness to participate and provide written informed consent;
- 3) ability to consume the test food product without adverse effects.

Participants in the DM group were identified based on a previous clinical diagnosis of diabetes mellitus documented in medical records or confirmed through ongoing treatment. Participants in the TB–DM group had a confirmed diagnosis of

active tuberculosis and diabetes mellitus, supported by clinical records and current anti-tuberculosis treatment at the time of recruitment.

Exclusion criteria were pregnancy, acute illness unrelated to tuberculosis, known allergy or intolerance to soy-based products, and any condition that could interfere with dietary intake or blood glucose measurement during the study period.

2.3. Ethical Considerations

The study was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval was obtained from The Ethical Review Board of Poltekkes Kemenkes Bandung (31/KEPK/EC/IV/2024) prior to data collection. All participants received detailed verbal and written explanations regarding study objectives, procedures, potential risks, and benefits. Written informed consent was obtained from all participants before enrolment. Participant confidentiality was strictly maintained, and all data were anonymised prior to analysis.

2.4. Test Food: Tempeh-based Functional Product (ATemp)

The test food used in this study was a tempeh-based functional product (ATemp), developed to provide a high-protein, culturally acceptable dietary option with favourable postprandial glycaemic characteristics. Tempeh was selected as the primary ingredient due to its widespread consumption, affordability, and established nutritional profile.

ATemp had previously undergone laboratory analysis to determine its nutrient composition, including macronutrient content, and glycaemic index using standard procedures. However, the present study did not aim to determine the glycaemic index of the product. Instead, the focus was on describing postprandial glycaemic responses following consumption under community-based conditions.

The product was prepared and portioned in a standardised manner to ensure consistency across participants. Portion size was determined based on typical serving sizes and practical dietary considerations rather than experimental glycaemic index protocols.

2.5. Study Procedure

Participants were instructed to abstain from food and caloric beverages for at least 8–10 hours prior to testing. On the day of assessment, participants arrived at the study site in a fasting state.

Fasting blood glucose (FBG) was measured using capillary blood sampling obtained via finger prick. Immediately after the fasting measurement, participants consumed a standard portion of ATemp under supervision to ensure complete intake.

Following consumption, participants remained at the study site and were instructed to avoid additional food intake and

strenuous physical activity. Two hours after consumption, capillary blood glucose was measured again to determine two-hour postprandial blood glucose (2h-PPG).

All blood glucose measurements were conducted using the same type of calibrated portable glucose monitoring device to minimise measurement variability. Testing procedures were standardised across all sites and participant groups.

2.6. Outcome Measurements

The primary outcome measures were: Fasting blood glucose (FBG), expressed in mg/dL and Two-hour postprandial blood glucose (2h-PPG), expressed in mg/dL.

Postprandial glycaemic response was assessed by examining the difference between fasting and postprandial glucose values within each participant and across study groups. The selected outcome measures reflect clinically relevant and feasible indicators commonly used in routine diabetes and tuberculosis care settings.

Assessment of postprandial glucose provides meaningful insight into the metabolic impact of foods, particularly in individuals with impaired glucose regulation. Two-hour postprandial glucose measurement is widely used in clinical practice and epidemiological research as an indicator of glycaemic control and diabetes-related risk.

Standard glycaemic index determination requires multiple blood sampling points and reference foods under tightly controlled conditions, which are often impractical in community-based studies involving vulnerable populations. The approach adopted in this study was intended to balance methodological rigour with feasibility and real-world applicability.

2.7. Data Management and Statistical Analysis

Data were entered into a secure database and checked for completeness and consistency prior to analysis. Descriptive statistical analyses were performed to summarise participant characteristics and glycaemic outcomes.

Continuous variables were presented as means, standard deviations, and minimum–maximum values. Glycaemic response patterns were examined by comparing fasting and postprandial glucose levels within and across groups. Given the descriptive nature of the study, no inferential statistical tests were applied, and findings were interpreted cautiously with emphasis on observed patterns rather than causal inference. All analyses were conducted using standard statistical software. Paired t-test was done to examine the difference between FBG and 2-h post prandial glucose with the 0.01 as the significance level.

This study was designed as an applied, community-based investigation to explore the practical implications of consuming a tempeh-based functional food among populations with differing metabolic conditions. The methodology prioritised feasibility, cultural relevance, and clinical applicability. While this approach limits causal interpretation, it provides valuable

real-world evidence to inform future controlled intervention studies.

3. Results

3.1. Participants Characteristics

A total of 178 adults participated in the study and were categorised into three groups based on metabolic and clinical status: non-diabetic (non-DM, $n = 100$), diabetic (DM, $n = 50$), and tuberculosis with diabetes (TB–DM, $n = 28$). Participant characteristics varied across groups in terms of age, sex, educational level, and occupational status.

Table 1. Subject Characteristics.

Characteristics	Subject groups		
	Non-DM	DM	TB-DM
Age, n (%)			
18-39 years old	63 (63)	1 (2)	21 (75)
40-59 years old	25 (25)	32 (64)	0 (0)
≥60 years old	12 (12)	17 (34)	7 (25)
Sex, n (%)			
Male	16 (16)	8 (16)	11 (39)
Female	25 (25)	42 (84)	17 (61)
Education, n (%)			
Elementary School	5 (5)	15 (30)	8 (29)
Junior High School	8 (8)	23 (46)	8 (29)
Senior High School	77 (77)	8 (18)	10 (35)
Higher Education	10 (10)	4 (8)	2 (7)
Occupation, n (%)			
Self-employment	8 (8)	11 (22)	7 (25)
Employee	7 (7)	3 (6)	3 (11)
Student	57 (57)	0 (0)	1 (3)
Housewife	28 (28)	36 (72)	17 (61)

Participants in the non-DM group were predominantly younger adults, with the majority aged between 18 and 39 years. In contrast, the DM group consisted mainly of middle-aged and older adults, with most participants aged 40 years or above. The TB–DM group showed a broader age distribution, including both younger and older adults, reflecting the epidemiological profile of tuberculosis in the study setting.

Female participants constituted the majority in all groups.

This predominance was particularly evident in the non-DM and DM groups, whereas the TB–DM group included a relatively higher proportion of male participants compared with the other groups. Educational attainment differed across groups, with higher education levels more common in the non-DM group, while lower levels of formal education were more frequently observed among participants in the DM and TB–DM groups.

Regarding occupation, students and formally employed individuals were more prevalent in the non-DM group, whereas housewives constituted most participants in both the DM and

TB–DM groups. These sociodemographic differences reflect underlying variations in lifestyle, socioeconomic background, and disease burden among the study populations.

3.2. Fasting Blood Glucose Levels

Fasting blood glucose (FBG) levels differed markedly across the three study groups. In the non-DM group, mean fasting glucose values were within the normal physiological range, indicating preserved baseline glycaemic regulation.

Table 2. Mean and standard deviation of blood glucose levels.

Variables	Subject groups		
	Non-DM	DM	TB-DM
Fasting plasma glucose, $\bar{x}$ ($\pm$ SD)	83.70 ($\pm$ 10.57)	170.40 ($\pm$ 67.56)	156.61 (75.18)
2-h post prandial glucose, $\bar{x}$ ($\pm$ SD)	90.29 ($\pm$ 23.39)	175.60 ($\pm$ 69.36)	159.50 (81.66)
Difference, $\bar{x}$ ($\pm$ SD)*	6.59 ($\pm$ 19.99)	7.30 ($\pm$ 15.80)	2.89 ($\pm$ 27.13)

*Not significant at 0.01

In contrast, participants in the DM and TB–DM groups exhibited substantially elevated fasting glucose levels. The DM group demonstrated the highest mean fasting glucose values, accompanied by a wide range of measurements, indicating considerable inter-individual variability. Similarly, the TB–DM group showed elevated fasting glucose levels, although the mean value was slightly lower than that observed in the DM group.

The wide range of fasting glucose values in both DM and TB–DM groups suggests heterogeneity in disease duration, metabolic control, and treatment status among participants. These fasting measurements provided an essential baseline for evaluating postprandial glycaemic responses following consumption of the tempeh-based functional food.

3.3. Two-hour Postprandial Blood Glucose Levels

Two-hour postprandial blood glucose (2h-PPG) levels measured after consumption of the tempeh-based functional food followed a pattern similar to fasting glucose levels across groups. In the non-DM group, postprandial glucose values remained within normal physiological limits, with only modest increases observed relative to fasting levels.

Among participants in the DM and TB–DM groups, postprandial glucose levels remained elevated in absolute terms, reflecting underlying chronic hyperglycaemia. However, the magnitude of postprandial increases following consumption of the tempeh-based product was limited. Mean postprandial

glucose values were only slightly higher than corresponding fasting levels.

Notably, despite elevated baseline glucose concentrations, participants in both the DM and TB–DM groups did not exhibit pronounced postprandial glucose spikes following intake of the tempeh-based functional food. This pattern indicates a relatively controlled postprandial glycaemic response across different metabolic conditions.

3.4. Postprandial Glycaemic Response Patterns

Postprandial glycaemic response was further assessed by examining the difference between fasting and two-hour postprandial glucose levels within each group. In the non-DM group, the mean difference between fasting and postprandial glucose values was small, reflecting stable glucose regulation following consumption of the test food.

Similarly, in the DM group, the mean postprandial increment was modest despite elevated fasting glucose levels. Although individual variability was observed, the overall pattern indicated that consumption of the tempeh-based functional food did not result in excessive postprandial glycaemic excursions.

The TB–DM group demonstrated the smallest mean difference between fasting and postprandial glucose levels among the three groups. While variability was greater in this group, the average postprandial change remained limited, suggesting that the test food was well tolerated from a glycaemic perspective.

tive even in the presence of concurrent infectious and metabolic disease.

3.5. Variability in Glycaemic Responses

Substantial inter-individual variability in both fasting and postprandial glucose levels was observed within the DM and TB–DM groups, as indicated by wide standard deviations and ranges. This variability likely reflects differences in disease severity, medication use, nutritional status, physical activity, and inflammatory burden.

Despite this heterogeneity, a consistent pattern was observed across all groups: postprandial glycaemic excursions following consumption of the tempeh-based functional food were modest relative to baseline glucose levels. This consistency across diverse metabolic profiles supports the robustness of the observed response patterns.

Comparative analysis across groups revealed clear differences in baseline glycaemic status, with the non-DM group exhibiting normal fasting glucose levels and the DM and TB–DM groups demonstrating elevated baseline values. However, postprandial changes remained relatively small in all groups.

The non-DM group showed stable fasting and postprandial glucose values with minimal fluctuation. In contrast, although the DM and TB–DM groups exhibited higher absolute glucose levels, they did not experience disproportionate postprandial increases following consumption of the tempeh-based functional food.

These findings indicate that baseline metabolic status largely determined absolute glucose concentrations, whereas consumption of the tempeh-based product did not substantially exacerbate postprandial glycaemic burden.

3.6. Summary of Key Findings

Overall, consumption of the tempeh-based functional food was associated with modest postprandial glycaemic responses among non-diabetic, diabetic, and TB–DM participants. Despite marked differences in baseline glycaemic status, postprandial glucose excursions remained limited across all groups.

These results provide descriptive evidence supporting the metabolic acceptability of tempeh-based functional foods in populations with varying degrees of glycaemic regulation, including individuals affected by TB–DM comorbidity.

4. Discussion

This study provides descriptive evidence on postprandial glycaemic responses following consumption of a tempeh-based functional food among adults with different metabolic conditions, including non-diabetic individuals, people with diabetes mellitus, and individuals with tuberculosis–diabetes (tb–dm) comorbidity. Despite substantial differences in baseline glycaemic status, postprandial glucose excursions after

intake of the tempeh-based product remained modest across all groups. Similar response patterns have been reported in previous studies examining fermented soy-based foods and postprandial glycaemia, particularly in populations with impaired glucose regulation [23, 27, 28].

4.1. Interpretation of Postprandial Glycaemic Responses

In non-diabetic participants, fasting and postprandial glucose levels remained within normal physiological ranges, reflecting preserved glucose homeostasis. This finding is consistent with earlier studies reporting stable glycaemic responses following consumption of fermented foods, which are known to slow carbohydrate digestion and absorption [18, 19]. Such responses support the metabolic safety of incorporating tempeh-based products into habitual diets among metabolically healthy individuals.

Among participants with diabetes mellitus, fasting glucose levels were markedly elevated, reflecting chronic hyperglycaemia and underlying insulin resistance. However, the observed postprandial glucose increments following consumption of the tempeh-based functional food were relatively small. This observation aligns with evidence indicating that foods rich in protein, fibre, and slowly digestible carbohydrates can attenuate postprandial glycaemic excursions in individuals with diabetes, even when baseline glycaemic control is suboptimal [15, 16, 19].

A similar pattern was observed in the tb–dm group. Although fasting glucose levels were elevated and inter-individual variability was considerable, postprandial increases remained limited on average. This finding is particularly relevant given that tb–dm comorbidity is frequently associated with metabolic instability, infection-related inflammation, and the metabolic effects of anti-tuberculosis therapy [6, 9, 29]. The results suggest that the tempeh-based functional food was well tolerated from a glycaemic perspective even in this vulnerable population.

4.2. Potential Mechanisms Underlying Moderated Glycaemic Responses

Several mechanisms may explain the moderated postprandial glycaemic responses observed following consumption of the tempeh-based functional food. Fermentation is known to induce structural modifications in starch, increasing the proportion of resistant and slowly digestible starch while reducing rapidly digestible fractions [20, 30]. These changes delay enzymatic hydrolysis in the small intestine, resulting in slower glucose absorption and attenuated postprandial glycaemic excursions [15, 20].

In addition, the high protein content of tempeh-based products may contribute to favourable postprandial responses. Dietary protein has been shown to stimulate insulin secretion, modulate incretin hormone release, and slow gastric emptying,

all of which influence postprandial glucose kinetics [19, 20]. The combined presence of protein and dietary fibre in tempeh-based foods may therefore create a macronutrient matrix that supports glycaemic stability [16, 19].

Fermentation also generates bioactive compounds, including peptides and isoflavone aglycones, which have been reported to exert antioxidant, anti-inflammatory, and insulin-sensitising effects [24-26]. These mechanisms are particularly relevant in populations characterised by chronic low-grade inflammation, such as individuals with diabetes or TB-DM comorbidity [9, 26]. Although such pathways were not directly examined in the present study, the observed postprandial glycaemic patterns are consistent with these proposed biological effects.

4.3. Relevance for Tuberculosis-diabetes Comorbidity

TB-DM comorbidity represents a growing clinical and public health challenge, particularly in low- and middle-income countries [1, 2, 6]. Individuals affected by both conditions face complex nutritional demands, including increased protein requirements to support infection recovery alongside the need to maintain glycaemic control [10, 11]. Inflammation associated with TB can further exacerbate insulin resistance and compromise metabolic regulation [6, 9].

Within this context, identifying foods that can provide adequate nutritional support without worsening glycaemic control is essential. The present findings suggest that tempeh-based functional foods may help address this dual challenge by offering a high-quality protein source without provoking excessive postprandial glycaemic stress. This characteristic is particularly valuable in community-based settings where access to specialised diabetic nutrition products is limited [11, 13].

Moreover, tempeh is widely consumed, affordable, and culturally acceptable in the study setting. These attributes enhance the feasibility and sustainability of dietary interventions based on tempeh-derived products. Compared with highly processed functional foods, tempeh-based foods can be integrated into existing dietary patterns with minimal behavioural change, thereby improving long-term adherence [14, 18].

4.4. Comparison with Existing Literature

Previous studies examining the glycaemic index or postprandial glycaemic response of tempeh and fermented soy products have generally reported favourable outcomes compared with refined carbohydrate foods or non-fermented soy products [23, 27, 28]. However, most of these studies were conducted in controlled laboratory settings or involved single-disease populations, limiting their generalisability to more complex clinical contexts.

The present study extends existing evidence by examining postprandial glycaemic responses in a real-world, community-

based setting and by including individuals with TB-DM comorbidity. Although differences in study design and outcome measures preclude direct comparison, the consistency of moderated postprandial responses across metabolic groups supports the potential role of tempeh-based foods as functional foods in diverse populations [18, 19].

4.5. Methodological Considerations and Limitations

Several limitations should be acknowledged. First, the descriptive and quasi-experimental design limits causal inference, as no control food or randomised comparison was included. Second, glycaemic measurements were limited to fasting and two-hour postprandial glucose levels, which do not capture the full postprandial glucose curve or glycaemic variability [15, 22]. Third, information on medication use, disease duration, and inflammatory markers was not incorporated, all of which may influence glycaemic responses, particularly in the DM and TB-DM groups [6, 9].

Despite these limitations, the study has notable strengths. It addresses an underexplored population, reflects real-world dietary practices, and focuses on a culturally relevant functional food. These features enhance the applicability of the findings and provide a strong foundation for future controlled intervention studies.

4.6. Implications for Functional Food Development and Future Research

From a functional food development perspective, the findings highlight the potential of traditional fermented foods as scalable nutritional interventions. Leveraging locally sourced ingredients such as tempeh may improve affordability, accessibility, and long-term adherence, particularly in resource-limited settings [14, 18].

Future research should employ randomised controlled designs, include appropriate comparator foods, and extend follow-up periods. Additional outcome measures, such as insulin response, inflammatory markers, glycaemic variability, and clinical outcomes related to TB treatment and diabetes control, would further elucidate the metabolic and health impacts of tempeh-based functional foods [9, 15, 16].

5. Conclusions and Recommendations

5.1. Conclusion

This study provides descriptive evidence on postprandial glycaemic responses following consumption of a tempeh-based functional food among non-diabetic individuals, people with diabetes mellitus, and individuals with tuberculosis-diabetes (TB-DM) comorbidity. Despite substantial differences

in baseline glycaemic status across groups, postprandial glucose excursions following intake of the tempeh-based product remained modest in all participants.

In non-diabetic individuals, postprandial glucose levels remained within normal physiological ranges, reflecting preserved glycaemic regulation. Among participants with diabetes and TB–DM comorbidity, absolute glucose concentrations were elevated as expected; however, postprandial increments relative to fasting values were limited. These findings suggest that the tempeh-based functional food did not exacerbate postprandial glycaemic burden, even in populations with impaired glucose regulation.

From a nutritional perspective, tempeh-based functional foods offer several advantages, including high-quality plant protein, dietary fibre, and fermentation-derived bioactive compounds that may support metabolic health. These attributes are particularly relevant for individuals with TB–DM comorbidity, who require adequate protein intake to support infection recovery while simultaneously maintaining glycaemic stability [10, 11]. By focusing on postprandial glycaemic responses under real-world community conditions, this study contributes novel evidence supporting the metabolic acceptability of culturally embedded functional foods in complex clinical nutrition contexts.

5.2. Recommendations

Based on the findings of this study, several recommendations can be proposed.

First, tempeh-based functional foods may be considered as culturally appropriate dietary options to support nutritional management among populations affected by diabetes and TB–DM comorbidity, particularly in low- and middle-income countries where tempeh is widely consumed, affordable, and socially accepted [1, 14]. Incorporation of such foods into community nutrition programmes or dietary counselling may help balance increased protein requirements and glycaemic considerations in a practical manner.

Second, future research should build upon the present findings by employing controlled intervention designs, including randomised controlled trials with appropriate comparator foods, to strengthen causal inference. More comprehensive assessment of postprandial glycaemic responses, such as multiple postprandial time-point measurements or continuous glucose monitoring, would provide deeper insight into glycaemic dynamics [15, 22].

Third, additional outcome measures should be explored to better understand the broader metabolic and clinical implications of tempeh-based functional foods. These may include insulin response, inflammatory markers, body composition, and clinical outcomes related to tuberculosis treatment and diabetes control, particularly in TB–DM populations characterised by chronic inflammation and metabolic instability [6, 9].

Finally, from a functional food development perspective,

further optimisation of tempeh-based products should consider sensory acceptability, portion size, and nutrient composition to maximise both metabolic benefits and long-term adherence. Leveraging traditional fermented foods as functional food platforms may offer a sustainable and scalable approach to addressing the intersecting challenges of infectious and metabolic diseases in resource-limited settings [18, 19].

Abbreviations

TB	Tuberculosis
DM	Diabetes Mellitus
FBG	Fasting Blood Glucose
LMICs	In Low and Middle-Income Countries

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Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



Hotma Rumahorbo is a professor at the Bandung Ministry of Health Polytechnic, specializing in nursing. He completed his doctoral degree in nursing at the University of Indonesia in 2012 and his master's degree in epidemiology at the same university in 2009. He contributes to research on non-communicable diseases, particularly diabetes, and is also active in various scientific activities, both as a seminar speaker and in community service activities. He contributes to the supervision and mentoring of doctoral nursing students and master's program students. He is actively involved as a research evaluator on the SIMLITABKES team at the Ministry of Health of the Republic of Indonesia.

Research Field

Hotma Rumahorbo: M. Epid.: Diabetes mellitus, Hemodialysis in kidney failure

Mutiara Syagita: Diabetes mellitus, Emergency care

Yohannes Willihelm Saleky: Product Development, Food Consumption Survey

Keiko Pasaribu: Tuberculosis