

**DEVELOPMENT OF A PLANT-BASED PATTY INCORPORATING
GREEN BANANA (*MUSA* SPP.) FLOUR AND WHITE OYSTER
MUSHROOM (*PLEUROTUS OSTREATUS*): PHYSICAL,
NUTRITIONAL, AND SENSORY EVALUATION**

by

TAN TZER FEN

Dissertation submitted in partial fulfillment of the requirements for

the degree of

Bachelor of Health Science (Honours)

(Nutrition)

January 2026

CERTIFICATE

This is to certify that the dissertation entitled “Development of A Plant-Based Patty Incorporating Green Banana (*Musa Spp.*) Flour and White Oyster Mushroom (*Pleurotus Ostreatus*): Physical, Nutritional, And Sensory Evaluation” is the bona fide record of research work done by Ms Tan Tzer Fen during the period from April 2025 to January 2026 under my supervision. I have read this dissertation and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation to be submitted in partial fulfillment for the degree of Bachelor of Health Science (Honours) (Nutrition).

Main supervisor,

.....

Professor Dr. Wan Rosli Wan Ishak

Lecturer

School of Health Sciences

Universiti Sains Malaysia

Health Campus

16150 Kubang Kerian

Kelantan, Malaysia

Date:

DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated and duly acknowledged. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at Universiti Sains Malaysia or other institutions. I grant Universiti Sains Malaysia the right to use the dissertation for teaching, research and promotional purposes.

.....

Tan Tzer Fen

Date:

ACKNOWLEDGEMENTS

First and foremost, I would like to express my deepest gratitude to my dedicated supervisor, Prof. Dr. Wan Rosli Wan Ishak, for his invaluable supervision, time, patience, persistent guidance and encouragement throughout this research. I also could not have undertaken this journey without the generous support from Dr. Johari bin Abdullah, who sponsored the mushrooms as the main ingredients for my patty development.

Additionally, I would like to thank all the staff in Nutrition Laboratory and Food Preparation Laboratory in the School of Health Sciences, USMKK. My sincere appreciation goes to them for their generous guidance, especially in operating the sophisticated instruments. Special thanks to research officer Dr. Nurraihana Hamzah for her advice and guidance on lab analyses. Furthermore, I would like to thank all my friends and colleagues, especially Farah, Mogesshini, Anis, Yi Jing, Izzah and others, for their unwavering support and assistance during the completion of my research.

Special thanks to my beloved family members for their moral support and endless love, which ensured the timely completion of my thesis. Lastly, heartfelt gratitude to all the volunteers for their interest, commitment, and time. Your kindness and contribution made this journey possible. Thank you very much.

TABLE OF CONTENTS

CERTIFICATE.....	ii
DECLARATION	iii
ACKNOWLEDGEMENTS.....	iv
LIST OF TABLES	viii
LIST OF FIGURES	ix
LIST OF SYMBOLS	x
LIST OF ABBREVIATIONS	xi
ABSTRAK.....	xii
ABSTRACT.....	xiv
CHAPTER 1 INTRODUCTION	1
1.1 Background of the Study	1
1.2 Problem Statement.....	5
1.3 Research Objectives.....	6
1.3.1 General Objectives.....	6
1.3.2 Specific Objectives	6
1.4 Study Hypothesis	7
1.4.1 Null Hypothesis	7
1.4.2 Alternative Hypothesis	7
1.5 Research Questions.....	7
1.6 Significance of the Study	8
CHAPTER 2 LITERATURE REVIEW	10
2.1 Overview of Plant-Based Meat Analogues.....	10
2.1.1 Global Trends and Demands for Plant-based Meat Analogues	10
2.1.2 Benefits of Plant-based Diets.....	12
2.1.3 Common Ingredients Used in Plant-based Meat Formulations.....	14
2.2 Green Bananas (<i>Musa</i> spp.).....	16
2.2.1 Nutritional Composition of Green Bananas.....	17
2.2.2 Applications of Green Bananas in Food Product Development	19
2.2.3 Preparation of Green Banana Flour	21
2.3 White Oyster Mushroom (<i>Pleurotus ostreatus</i>).....	22
2.3.1 Nutritional Composition of White Oyster Mushroom (<i>Pleurotus ostreatus</i>) 23	
2.3.2 Applications of White Oyster Mushroom (<i>Pleurotus ostreatus</i>) in Food Product Development	25

2.4	Chickpea	26
2.4.1	Nutritional Composition of Chickpea.....	26
2.4.2	Health Benefits of Chickpea	28
2.4.3	Applications of Chickpea in Food Product Development	28
2.5	Tempeh.....	29
2.6	Red Dragon Fruit	30
2.7	Research Gap and Future Directions	31
CHAPTER 3 METHODOLOGY		32
3.1	Materials and Methods.....	32
3.2	Study Design.....	32
3.3	Study Location.....	33
3.4	Selection Criteria	33
3.4.1	Inclusion Criteria	33
3.4.2	Exclusion Criteria	33
3.5	Sampling Method.....	33
3.6	Sample size calculation.....	34
3.7	Research Tool.....	34
3.8	Data Collection	35
3.8.1	Preparation of raw material.....	35
3.8.2	Ingredients list.....	36
3.8.3	Preparation of Ingredients.....	37
3.9	Cooking Characteristics	42
3.9.1	Cooking Yield (%)	42
3.9.2	Moisture retention (%).....	43
3.9.3	Diameter reduction (%)	43
3.10	Physical Properties.....	43
3.10.1	Texture Profile Analysis (TPA).....	43
3.10.2	Colour Analysis.....	44
3.11	Nutritional Composition	45
3.11.1	Moisture Content	46
3.11.2	Ash Content	47
3.11.3	Protein Content	49
3.11.4	Fat Content.....	51
3.11.5	Carbohydrate.....	52
3.11.6	Crude Fibre	53

3.11.7	Calorific Value	56
3.12	Sensory Evaluation	56
3.13	Study Flowchart.....	58
3.14	Data analysis	58
3.15	Ethical consideration.....	59
CHAPTER 4 RESULTS AND DISCUSSION		61
4.1	Nutritional Composition of Green Banana Flour and Chickpea Flour	61
4.2	Cooking Characteristics of Cooked Plant-based Patties.....	63
4.3	Physical Properties of Cooked Plant-based Patties.....	65
4.3.1	Texture Profile Analysis of Cooked Plant-based Patties	65
4.3.2	Colour Properties of Raw and Cooked Plant-based Patties	68
4.4	Nutritional Composition of Raw and Cooked Plant-based Patties	71
4.5	Sensory Evaluation of Cooked Plant-based Patties	83
CHAPTER 5 CONCLUSION		87
5.1	Conclusion	87
5.2	Recommendations for Future Study	88
REFERENCES		89
APPENDICES		104
Appendix A: Advertisement for Subject Requirement		104
Appendix B: Research Information and Consent Form.....		105
Appendix C: Sensory Evaluation Form		111
Appendix D: White Oyster Mushroom (<i>Pleurotus ostreatus</i>) Cultivation Farm.....		112
Appendix E: Table II Conditions for Nutrient Contents for Use of Nutrition		113
Claims		
Appendix F: Ethical Approval Letter.....		114

LIST OF TABLES

Table 3.1 List of Ingredients for Plant-based Patty	37
Table 3.2 Plant-based Patties Formulated with Different Levels of Green Banana Flour	42
Table 4.1 Nutritional Composition of Green Banana Flour and Chickpea Flour	63
Table 4.2 Cooking Characteristics of Cooked Plant-based Patties Incorporated with Different Levels of Green Banana Flour	65
Table 4.3 Texture Profile Analysis of Cooked Plant-based Patties Incorporated with Different Levels of Green Banana Flour	68
Table 4.4 Colour Properties of Raw Plant-based Patties Incorporated with Different Levels of Green Banana Flour	69
Table 4.5 Colour Properties of Cooked Plant-based Patties Incorporated with Different Levels of Green Banana Flour	71
Table 4.6 Nutritional Composition of Raw Plant-based Patties Incorporated with Different Levels of Green Banana Flour	75
Table 4.7 Nutritional Composition of Cooked Plant-based Patties Incorporated with Different Levels of Green Banana Flour	83
Table 4.8 Sensory Attributes of Cooked Plant-based Patties Incorporated with Different Levels of Green Banana Flour (n=50)	86

LIST OF FIGURES

Figure 2.1: Standard Commercial Colour Chart for Ripening Stages	17
Categorisation	
Figure 3.1 White Oyster Mushroom Collected from MACMA	36
Figure 3.2 Processing of White Oyster Mushroom in a Food Processor	37
Figure 3.3 Processing of Tempeh in a Food Processor	38
Figure 3.4 Food Blender	39
Figure 3.5 The blended mixture was spread evenly on a baking tray with parchment paper	39
Figure 3.6 Hot air oven	40
Figure 3.7 Raw plant-based patties with different levels of green banana flour	41
Figure 3.8 Cooked plant-based patties with different levels of green banana flour	41
Figure 3.9 Texture analyser	44
Figure 3.10 Portable Spectrophotometer	45
Figure 3.11 Blender for Homogenisation of Sample	46
Figure 3.12 Hot Air Oven for Determination of Moisture Content	47
Figure 3.13 Electric Hotplate for Determination of Ash	48
Figure 3.14 Muffle Furnace for Determination of Ash	49
Figure 3.15 Digestion Process of Protein Analysis	50
Figure 3.16 Distillation Process Followed by Automated Titration Process	50
Figure 3.17 Semi-automatic Solvent Extractor for Determination of Fat	52
Figure 3.18 Fibertec Extraction System for Determination of Crude Fibre	54
Figure 3.19 Drying Oven	55
Figure 3.20 Muffle Furnace for Determination of Crude Fibre	55
Figure 3.21 Samples Presented to Each Panellist	57

LIST OF SYMBOLS

\$	US Dollar
%	Percentage
<	Lower than
>	Greater than
$\leq$	Lower than or equal to
$\geq$	Greater than or equal to
$\pm$	Plus-minus
$^{\circ}\text{C}$	Degree Celsius
cm	Centimetre
g	Gram
hr	Hour
kcal/100g	kilocalorie per one hundred gram
kg	Kilogram
min	Minute
mL	Millilitre
Mm	Millimetre
mm/s	Millimeters per second
p	p-value
s	Seconds
$\text{TgCO}_2\text{eq yr}^{-1}$	Teragrams of carbon dioxide equivalent per year
w/v	Weight per volume
w/w	Weight per weight

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
CHO	Carbohydrate
et al.	And others
FAO	Food and Agricultural Organization
GHG	Greenhouse gas
GI	Glycaemic index
H ₂ SO ₄	Sulphuric acid
H ₃ BO ₃	Boric acid
LDL	Low-density lipoprotein
MACMA	Malaysian Chinese Muslim Association
NaOH	Sodium hydroxide
NRV	Nutrient Reference Value
PSC	<i>Pleurotus sajor-caju</i>
RS	Resistant starch
SCFAs	Short-chain fatty acids
SDGs	Sustainable Development Goals
spp.	Species (plural)
SPSS	Statistical Package for Social Science
TPA	Texture Profile Analysis
TVP	Texturised vegetable protein
UK	United Kingdom
US	United States
USMKK	Universiti Sains Malaysia Health Campus

**PENGHASILAN PATTI BERASAKAN TUMBUHAN
MENGUNAKAN TEPUNG PISANG HIJAU (*MUSA SPP.*) DAN
CENDAWAN TIRAM PUTIH (*PLEUROTUS OSTREATUS*):
PENILAIAN FIZIKAL, NUTRISI DAN SENSORI**

ABSTRAK

Analog daging berasaskan tumbuhan telah menjadi semakin popular disebabkan oleh kesedaran pengguna terhadap kelestarian alam sekitar, kebajikan haiwan dan risiko kesihatan yang dikaitkan dengan pengambilan daging. Cendawan tiram putih (*Pleurotus ostreatus*) berpotensi sebagai analog daging kerana membekalkan kandungan nutrien yang tinggi dan manfaat kesihatan. Pisang (*Musa spp.*) dikeluarkan dan dimakan secara meluas di seluruh dunia, tetapi sejumlah besar telah dibuang kerana kualiti yang kurang memuaskan. Pisang hijau berpotensi digunakan sebagai bahan baharu untuk meningkatkan profil pemakanan sambil mengurangkan pembaziran. Kajian ini menilai kesan penggantian sebahagian tepung kacang kuda dengan tepung pisang hijau (0, 25, 50, 75 dan 100%) terhadap sifat fizikal, komposisi pemakanan dan penerimaan sensori patti berasaskan tumbuhan (*plant-based patty*). Keputusan kajian menunjukkan peningkatan yang ketara ($p<0.05$) dalam hasil masakan (*cooking yield*) dan profil pemakanan patti berasaskan tumbuhan dengan peningkatan kandungan tepung pisang hijau. Penggantian 100% merekodkan hasil masakan tertinggi ($p<0.05$) pada 85.67% dan pengurangan diameter terendah pada 1.46%. Kandungan lemak dan nilai kalori menurun selaras dengan peningkatan kandungan tepung pisang hijau dalam patti berasaskan tumbuhan yang dimasak. Patti tepung pisang hijau 100% mencatatkan kandungan lemak (5.02%) dan nilai kalori (223.05 kcal/100g) terendah ($p<0.05$). Patti berasaskan tumbuhan yang

diformulasikan dengan 25% tepung pisang hijau mempunyai kandungan protein yang lebih rendah (15.87%) berbanding patti kawalan (15.92%), tetapi perbezaan tidak ketara. Sifat tekstur patti berasaskan tumbuhan tidak terjejas kecuali kepaduan. Penambahan tepung pisang hijau yang lebih tinggi (75%-100%) telah menggelapkan warna dan mengurangkan skor rupa dan warna. Nilai kecerahan (L^*) dan kekuningan (b^*) dalam patti berasaskan tumbuhan yang dimasak menurun ($p < 0.05$) dengan peningkatan tepung pisang hijau. Penerimaan sensori untuk patti yang diformulasikan dengan 25% tepung pisang hijau adalah setanding dengan patti kawalan. Kesimpulannya, penggantian tepung kacang kuda dengan tepung pisang hijau pada 25% disyorkan untuk mengurangkan kandungan lemak dan kalori tanpa menjejaskan kandungan protein dan penerimaan sensori. Kajian ini menunjukkan bahawa tepung pisang hijau merupakan bahan masakan tempatan yang mampan dalam penghasilan patti berasaskan tumbuhan.

DEVELOPMENT OF A PLANT-BASED PATTY INCORPORATING GREEN BANANA (*MUSA* SPP.) FLOUR AND WHITE OYSTER MUSHROOM (*PLEUROTUS OSTREATUS*): PHYSICAL, NUTRITIONAL, AND SENSORY EVALUATION

ABSTRACT

Plant-based meat analogues have become increasingly popular due to concerns over the environmental sustainability, animal welfare and health risks associated with meat consumption. White oyster mushroom (*Pleurotus ostreatus*) serves as a promising plant-based meat analogue due to its nutritional and health benefits. Bananas (*Musa* spp.) are widely produced and consumed globally, but a significant amount is discarded during the grading process due to substandard qualities. Green bananas could potentially be used as a novel ingredient to improve the nutritional profile of food while combating post-harvest loss. This study evaluated the effect of partially substituting chickpea flour with green banana flour (0, 25, 50, 75 and 100%) on the physical properties, nutritional composition and sensory acceptability of plant-based patties. Results revealed significant improvements ($p<0.05$) in cooking yield and nutritional profile of plant-based patties with green banana flour incorporation. The 100% substitution yielded the highest cooking yield ($p<0.05$) at 85.67% and the lowest diameter reduction at 1.46%. Fat content and calorific value decreased in line with the green banana flour levels in cooked plant-based patties. 100% green banana flour patty recorded the lowest ($p<0.05$) fat content (5.02%) and calorific value (223.05 kcal/100g). Cooked plant-based patty formulated with 25% green banana flour had a lower protein content of 15.87% than the control patty (15.92%), but it was not significant. The textural properties of plant-based patties were not affected

except for cohesiveness. However, higher levels of green banana flour incorporation (75%-100%) darkened the colour, thus reducing the appearance and colour scores. The lightness (L^*) and yellowness (b^*) values in cooked plant-based patties decreased ($p<0.05$) with increasing levels of green banana flour. All sensory attributes of the plant-based patty formulated with 25% green banana flour were comparable to the control patty. In summary, the incorporation of green banana flour at 25% to partially replace the chickpea flour can be recommended to lower fat and calorific value without compromising protein or sensory acceptability. This study demonstrated that green banana flour serves as a locally sourced, sustainable ingredient for plant-based patties.

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The world's population is expected to surpass 9 billion people by 2050, which suggests that food consumption will increase. Hence, agricultural production will have to expand by 70% to meet the rising demand for food (Food and Agriculture Organization, 2019). Consequently, the demand for protein will also increase globally. Animal proteins are considered complete proteins because they contain all nine essential amino acids. However, their production is economically and environmentally costly, contributing significantly to global emissions and resource depletion. Globally, our current meat production and consumption patterns are considered socially and environmentally unsustainable (Malek et al., 2019). The environmental impact of meat production is significant, contributing to increasing carbon emissions, land use, and greenhouse gas (GHG) emissions, which exacerbate biodiversity loss and climate change (Malek et al., 2019; Profeta et al., 2021; Teresa & Pag, 2021). GHG emissions were measured in teragrams of carbon dioxide equivalent per year ($\text{TgCO}_2\text{eq yr}^{-1}$). According to Xu et al. (2021), global GHG emissions from food production amount to $17,318 \pm 1,675 \text{ TgCO}_2\text{eq yr}^{-1}$, which are primarily driven by animal-based foods, which account for 57% of the total, followed by plant-based foods at 29%, and other uses at 14%. In short, our global GHG emissions from animal-based foods are twice those of plant-based foods. This is because plant protein production generally requires less land, water, and energy than animal protein production and thus results in less GHG emissions (Lynch et al., 2018). Hence, meat substitutes or meat analogues have

been proposed as a solution to combat the adverse environmental effects and demand gap related to meat.

Additionally, red and processed meats have been positively associated with all-cause mortality (Rohrmann et al., 2013). The impact is most notable for cancers. According to the International Agency for Research on Cancer (2015), red meat is classified as "probably carcinogenic to humans," especially colorectal cancer, as well as pancreatic and prostate cancers. Furthermore, consuming a 50-gram portion of processed meat daily increases the relative risk of colorectal cancer by 18%. Moreover, processed meat is high in cholesterol and saturated fatty acids, which will increase the risk of coronary heart disease and diabetes (Micha et al., 2010).

Increasing evidence suggests that a shift towards more plant-based protein sources can provide benefits at both individual and societal levels. For instance, vegetarians generally have better cardiovascular health and lower risks of diseases like cardiovascular disease, certain cancers, diabetes, and metabolic syndrome compared to those on omnivorous diets. Furthermore, vegetarians tend to have lower overall mortality rates (Lynch et al., 2018). As awareness of these issues grows, consumers are gradually shifting to healthier dietary options, such as plant-based diet, vegan and vegetarian diet. As a result, the popularity of plant-based meat substitutes has surged in the past decade due to concerns over the health risks associated with meat consumption as well as environmental sustainability and animal welfare. Therefore, alternative protein products such as legume-based patties and mushroom-based meat analogues, which have been around for many decades and were once considered a niche sector of the food industry, are now expanding rapidly in the market (Sha & Xiong, 2020).

As the demand for plant-based proteins is increasing globally, the plant-based meat market is expected to experience significant growth in the coming years. According to Grand View Research (2023), the market was valued at approximately \$7.17 billion in 2023 and is projected to grow at a compound annual growth rate of 19.4% from 2024 to 2030, reaching an estimated \$24.77 billion by the end of the forecast period. This rapid growth is driven by increasing consumer awareness of the health benefits of plant-based diets, environmental concerns, and the rising popularity of vegan and flexitarian lifestyles. The plant-based meat market has potential for further expansion and innovation as demand for sustainable and healthier food alternatives increases.

Meat analogues, also known as meat substitutes, are manufactured from non-meat protein sources, thus offering a plant-based alternative to traditional meat. Meat analogues primarily rely on texturised vegetable proteins (TVPs), which are derived from soy, wheat, or pea proteins and their mixtures, with texturised soy protein being the most widely used in commercially available plant-based meat substitutes (Kaczmarska et al., 2021; Kyriakopoulou et al., 2021). Manufacturers tend to attempt to replicate the flavour, texture, mouthfeel and nutritional content of meat such as beef, chicken, or pork (Kumar et al., 2017). As existing meat analogue products predominantly rely on soy and wheat, this study aims to explore locally available plant-based material such as green bananas as a novel ingredient to address the heavy reliance on soy and wheat in existing products.

Bananas are one of the widely produced and consumed fruits globally, especially in tropical regions such as Malaysia and Thailand. It is a large herbaceous plant that belongs to the genus *Musa* from the family *Musaceae* (Afzal et al., 2022). According to Jiang et al. (2015), almost one-third of all bananas harvested are discarded since consumers often prefer ripe bananas. Additionally, since banana is a climacteric fruit,

ripe bananas are prone to mechanical damage and are perishable during the maturation process, which makes their storage and transport difficult. Furthermore, approximately 20% of banana production is not commercialised due to size and appearance flaws (Alves et al., 2016). Similarly, according to Thakaeng et al. (2021), a significant number of bananas (*Cavendish* spp.) cultivated in Chiang Rai province, northern Thailand, are rejected during the grading process due to similar reasons. It is crucial to address this post-harvest loss through the utilisation of rejected bananas to enhance profitability and support sustainability. Additionally, bananas are popular with their good nutritional profile and are a good source of many macronutrients, micronutrients, and phytonutrients (Falcomer et al., 2019; Netshiheni et al., 2020). Despite studies showing the health benefits of green bananas, limited research has explored their possible usage in food products, particularly in plant-based meat analogues. Hence, it is crucial to explore the potential of green bananas for use in the plant-based protein food industry to combat food wastage while improving the nutritional profile.

Pleurotus ostreatus, commonly known as the white oyster mushroom, is widely cultivated globally due to its ability to be cultivated simply and cheaply with high yield. It is valued for its nutritional and health benefits, such as high proteins, carbohydrates, minerals, vitamins, antioxidants, phytochemicals and low in fat. It has the potential to be a meat alternative due to its quality protein and essential amino acids (Effiong et al., 2024). Additionally, the bioactive compounds such as polysaccharides, phenolic compounds, and flavonoids present in white oyster mushroom have various therapeutic properties such as antioxidant, anti-carcinogenic, antibacterial, antidiabetic, anti-atherogenic, immunomodulatory and others (Sreedharan et al., 2025). Previous studies have shown that the incorporation of white oyster mushroom can improve the nutritional value of various food products, including

processed meats, noodles, bread and other baked products (Parvin et al., 2020; Putri et al., 2021; Stępniewska et al., 2025).

This study aims to develop a plant-based patty that incorporates green banana (*Musa* spp.) flour and white oyster mushroom (*Pleurotus ostreatus*). By exploring the potential usage of green bananas, this research seeks to contribute valuable insights that can reduce overreliance on soy proteins in the development of plant-based foods. Additionally, this research hopes to encourage a more environmentally friendly plant-protein food choice to reduce the significant environmental footprint associated with the production of animal-protein foods.

1.2 Problem Statement

The global demand for plant-based meat alternatives has surged in recent years, driven by growing concerns about health, environmental sustainability, and animal welfare (Sha & Xiong, 2020). However, many existing plant-based products rely heavily on soy, wheat gluten, or highly processed ingredients, which may not align with consumer expectations for minimally processed and sustainable options. Meanwhile, bananas are abundantly available in tropical countries like Malaysia, providing a locally sourced, sustainable, and underutilised raw material that can be leveraged to develop plant-based products. A significant amount of bananas are rejected due to undesirable maturity, size, and appearance (Jiang et al., 2015; Alves et al., 2016; Thakaeng et al., 2021). This will lead to food wastage if they are not utilised properly.

Therefore, there is a need to explore the use of locally sourced, sustainable ingredients such as green banana flour to develop plant-based patties, thereby reducing

food waste and enhancing the nutritional profile of patties. This study aims to develop a plant-based patty from green banana flour and white oyster mushroom. In this study, we will also compare different formulations of patties that have been developed with varying amounts of green banana flour in terms of their nutritional composition, physical properties and sensory evaluation.

1.3 Research Objectives

1.3.1 General Objectives

To develop and evaluate plant-based patties incorporating green banana flour and white oyster mushroom with different ratios of green banana flour and chickpea flour.

1.3.2 Specific Objectives

- i. To develop plant-based patties with different ratios of green banana flour and chickpea flour.
- ii. To compare the nutritional and physical profiles of plant-based patties prepared with different ratios of green banana flour to chickpea flour.
- iii. To compare the sensory acceptability of plant-based patties prepared with different ratios of green banana flour to chickpea flour.

1.4 Study Hypothesis

1.4.1 Null Hypothesis

There is no significant difference in nutritional, physical, and sensory properties of plant-based patties developed with varying ratios of green banana flour and chickpea flour.

1.4.2 Alternative Hypothesis

There is a significant difference in nutritional, physical, and sensory properties of plant-based patties developed with varying ratios of green banana flour and chickpea flour.

1.5 Research Questions

- i. How can plant-based patties be formulated using different ratios of green banana flour and chickpea flour?
- ii. How do the nutritional and physical profiles of plant-based patties vary with different ratios of green banana flour to chickpea flour?
- iii. How does the sensory acceptability of plant-based patties vary with different ratios of green banana flour to chickpea flour?

1.6 Significance of the Study

The increasing demand for plant-based food products in the coming years justifies the need for novel ingredients to be used in the meat analogue to reduce heavy reliance on soy and wheat. This shift will not only promote dietary diversity but also support environmental sustainability, aligning with the Sustainable Development Goals (SDGs). SDG 2: Zero Hunger is addressed by incorporating underutilised locally sourced ingredients that can improve nutrition and promote sustainable agriculture. SDG 3: Good Health and Well-being can be supported by encouraging healthier dietary patterns through increased consumption of plant-based foods, thereby lowering the risks of non-communicable diseases associated with high meat intake. SDG 12: Responsible Consumption and Production can be achieved by reducing food waste through the application of underutilised agricultural byproducts such as red dragon fruit peel in food product development (United Nations, 2015).

Furthermore, the findings of this study will benefit consumers by offering a broader range of plant-based proteins and meat alternatives. This will provide consumers with more options that cater to their preferences and budget constraints. Additionally, a sensory evaluation will be conducted to assess the overall acceptability of the plant-based patty based on panellists' preferences regarding appearance, taste, mouthfeel, and other attributes. This evaluation is crucial in determining consumer acceptance of the plant-based patty developed from green banana flour and white oyster mushroom.

This study aims to determine the best formulation for developing a plant-based patty from green banana flour and white oyster mushroom. Additionally, a comparison between different formulations of plant-based patties based on nutritional and physical profiles will reveal any differences. Hence, food manufacturers will be guided on the

formulation to produce a meat analogue with desirable physical, sensory and nutritional properties.

Next, this study will help researchers identify critical areas within the plant-based meat market that have yet to be explored. The findings from this research could provide valuable insights into the utilisation of green banana and red dragon fruit peel in food product development. By exploring these underutilised resources, we can contribute to better food waste reduction and management strategies, ultimately leading to a decrease in carbon footprint over time.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Plant-Based Meat Analogues

Meat analogues, also known as meat alternatives or meat substitutes, are food products that are developed from non-animal protein sources. They are developed to mimic the taste and texture of meat and are consumed as an alternative to traditional meat (Knaapila et al., 2022). The most commonly used alternative protein ingredients originate from plants, particularly wheat and legumes like soy or pea. Other alternative protein sources are fungi, insects, and algae (Bleakley & Hayes, 2017; Thavamani et al., 2020; Alcorta et al., 2021). With numerous meat alternatives available in the market, plant-based proteins have emerged as the most widely accepted meat alternatives from the consumer's perspective (Onwezen et al., 2020).

2.1.1 Global Trends and Demands for Plant-based Meat Analogues

In recent years, the popularity of these meat analogues has surged exponentially as more consumers seek more sustainable, ethical, and healthier options to meet their protein intake. According to the FAO (2014), sustainability in food systems refers to ensuring that the future food and nutrition security of future generations is not compromised due to the depletion of economic, social, and environmental resources. The global shift toward sustainable protein sources and health-conscious diets has led to the rapid evolution of the plant-based meat market, with many new companies producing meat analogues that have been founded recently.

According to Realini et al. (2023), the global meat analogues industry is projected to reach a value of \$8.1 billion by 2026.

According to Dagevos (2021), the global meat analogues market is targeted not only toward vegans and vegetarians but also toward flexitarians. A flexitarian is an individual who eats mostly vegetarian food but occasionally consumes meat or fish (Derbyshire, 2017). Flexitarians are not a homogeneous group that follows a strict diet, but instead they represent a middle category between consumers who regularly eat meat and those who fully abstain from it. A flexitarian reduces meat consumption by occasionally refraining from eating meat. They only mildly reduce their meat intake without eliminating it.

Dietary patterns have a profound impact on both the environment and individual health. To address health and environmental challenges, one effective strategy for a more sustainable diet is to substitute meat with alternative protein sources. Consumers can include various sources of proteins in their diets by replacing meat with a meat analogue, or opting for seaweed or beans as alternative proteins in their dishes (Onwezen et al., 2020). Supermarkets and restaurants are increasingly offering alternatives to traditional meat products to meet the rising demand for plant-based food. For instance, in the chilled cabinets at the supermarket, items that look like chicken, sausages, and burger patties are displayed next to meat. These alternatives directly mimic traditional meat products and are designed to replicate the texture and qualities of meat (Curtain & Grafenauer, 2019).

2.1.2 Benefits of Plant-based Diets

Shifting away from meat-heavy diets towards diets containing more plant-based food is generally better for the environment and individual health (Dagevos, 2021). According to Poore and Nemecek (2018), this shift in dietary pattern is necessary because the production of animal products offers only 37% of protein and 18% of calories, yet it consumes around 83% of the world's farmland and produces 56% to 58% of emissions. Plant protein production generally requires less land, water, and energy than animal protein production and thus results in less greenhouse gas (GHG) emissions.

Plant-based diets are rich in whole grains, legumes, nuts, and dried fruit, which are high in dietary fibres and have a low glycaemic index (GI). Dietary fibres are the key fermentable substrates for the proliferation of beneficial bacteria Bacteroidetes and the production of short-chain fatty acids (SCFAs) such as acetate, propionate, and butyrate (Losno et al., 2021; Dietrich et al., 2022). Additionally, dietary fibres and phytosterols reduce the reabsorption of cholesterol and bile acids in the small intestine, thus resulting in an increased low-density lipoprotein (LDL) uptake by the liver (Wang et al., 2023). As a result, plasma cholesterol levels particularly LDL is lower among vegetarians.

Well-planned plant-based diets can provide a wide range of vitamins, minerals, and phytochemicals that are protective against oxidative stress and inflammation. According to Liguori et al. (2018), findings suggest an inverse relationship between antioxidant and polyphenol intake and the risk of developing chronic diseases, including diabetes, cardiovascular diseases, cancer, and potentially dementia. Similarly, research conducted by Rudrapal et al. (2022) suggests that regular consumption of polyphenol-rich foods is associated with reduced oxidative stress,

inflammation, and cellular damage, which are key contributors to these conditions. Additionally, plant-based diets which are high in antioxidants and phytochemicals may reduce the risk of developing atherosclerotic plaques via adaptive modulations of stress-response enzymes and receptors that prevent lipoprotein oxidation, endothelial dysfunction, and immune activation (Björkegren & Lusis, 2022).

Plant proteins generally have a lower protein efficiency than animal-derived proteins. Additionally, plant-based diets are lower in micronutrients especially iron and vitamin B12 (Neufingerl & Eilander, 2021). Few researchers (Neufingerl & Eilander, 2021; Wang et al., 2023) have suggested that plant-based diets may be lower in micronutrients, potentially placing vegans and some vegetarians at risk of deficiencies in vitamins and minerals such as vitamin B12, riboflavin, iron, zinc, calcium, and omega-3 fatty acids. Additionally, plant-based diets might place pregnant women at risk of nutrient deficiencies if the protein and micronutrient sources in the diet are not diverse, affecting the growth and development (Meulenbroeks et al., 2021). However, according to Baroni et al. (2018), a well-planned plant-based diet can mitigate these risks and adequately meet the nutritional needs of pregnant and lactating women, as well as children, provided it includes all plant-based food groups and ensures the intake of critical nutrients from diverse sources. Additionally, food preparation techniques should be considered to optimise nutrient availability and adequacy.

2.1.3 Common Ingredients Used in Plant-based Meat Formulations

The plant-based meat formulation includes proteins, fats and carbohydrates as the major ingredients responsible for texture. Minor components are added to enhance flavour, produce a desired colour change when cooked, and provide micronutrients for fortification (Tyndall et al., 2022).

Proteins are included as a major ingredient not only due to their nutritional properties, but also due to their physical functional roles in food such as water holding capacity and gelling properties (Loveday, 2020). Proteins are usually texturised before being included in formulations, resulting in the production of texturised vegetable protein (TVP). Traditionally, soy and wheat proteins were used in developing plant-based food products. However, few researchers (Bohrer, 2019; Sha & Xiong, 2020) suggested that proteins from other sources such as barley, oats, pea, potato, mung bean, lentil, lupin, chickpea and rice protein are becoming more popular among plant-based meat manufacturers in recent years. Traditional high-protein soy-based foods such as tofu, tempeh, and natto have been widely consumed in Asia for generations. According to Nout and Kiers (2005), raw tempeh has a pleasant, slightly fermented odour. After grilling or frying at high temperatures, tempeh may develop desirable "meaty" and "nutty" flavours. Similarly, tempeh offers a natural umami flavour and dense texture, often preferred by consumers who prefer a more meat-like eating experience (Romulo & Surya, 2021). Hence, this research will also utilise tempeh as a sub-ingredient to develop the plant-based patty.

In the development of plant-based meat analogues, many types of carbohydrates have been included to enhance the product's flavour, texture, and structural integrity. Polysaccharides such as flour, methylcellulose, acacia gum, xanthan gum, carrageenan, potato starch, native and modified starch, are included as

binders to improve the texture and consistency of products (Bohrer, 2019; Boukid, 2020; McClements & Grossmann, 2021). Additionally, a few researchers (Palanisamy et al., 2018; Bakhsh et al., 2021; Nanta et al., 2021) suggested that careful selection of carbohydrates based on type and concentration used as the non-adhesive binding agent is crucial to improve the quality of the formulated product. For instance, the addition of 1.5% iota-carrageenan can enhance the texture of soy meat substitutes produced by high moisture extrusion. Blends of κ -carrageenan/xanthan gum or guar gum/xanthan gum have the potential to be used in the production of gluten-free meat substitutes that are based on soy protein with a nice texture. Another study found that the best amount of methylcellulose to improve physiochemical properties, texture, and sensory quality in a plant-meat substitute patty was 3%.

It has been challenging to replace animal fats with natural fats or oils derived from plants. According to Bohrer (2019), coconut oil, sunflower oil, and canola oil are commonly used in developing commercial plant-based meat substitutes. Other potential sources of higher solid fats include cocoa butter in 3D printed plant-based meat substitutes (Wang & Liu, 2021) and specialty palm and shea butter fats for vegetarian burgers (Southey, 2019). However, choosing the right kind of fat has an impact on the nutritional value, whereby more saturated and harder fats are less desirable from a nutritional perspective.

According to Tyndall et al. (2022), the functional ingredients added to a plant-based formulation include vitamins, preservatives, food colouring, and flavour precursors. Flavouring agents such as yeast extract, salt, paprika, sugar, herbs and spices have been used. For desirable meat colour, lycopene, beetroot juice, and soy leghemoglobin have been utilised (Boukid, 2020). In this study, red dragon fruit flesh and peel powder were proposed as a natural food colouring to mimic the red-pink

appearance of meat, aligning with the reduction of food waste and promoting environmental sustainability.

2.2 Green Bananas (*Musa* spp.)

Bananas are large herbaceous plants that belong to the genus *Musa* from the family Musaceae (Afzal et al., 2022). Bananas are widely produced and consumed globally, particularly in tropical regions such as Malaysia and Thailand. In Chiang Rai province, northern Thailand, a significant quantity of green Cavendish bananas (*Musa acuminata*) is cultivated, with most exported to China. However, a significant amount of bananas are discarded during the grading process because they fail to meet the desired standards for size and ripeness (Thakaeng et al., 2021).

During banana maturation, the colour of the banana peels will change significantly from green to yellow. According to Maduwanthi and Marapana (2017), this colour transformation is due to chlorophyll degradation. Figure 2.1 shows the classification of standard commercial colour charts of the banana maturation into seven stages: Stage 1 are fully green bananas; Stage 2, green with a trace of yellow; Stage 3, predominantly green with some yellow; Stage 4, predominantly yellow with some green; Stage 5, yellow with a trace of green; Stage 6, fully yellow; and Stage 7, fully yellow with brown spots (Mathias et al., 2021). Green banana flour produced from stage 1 green bananas was used in the present study.

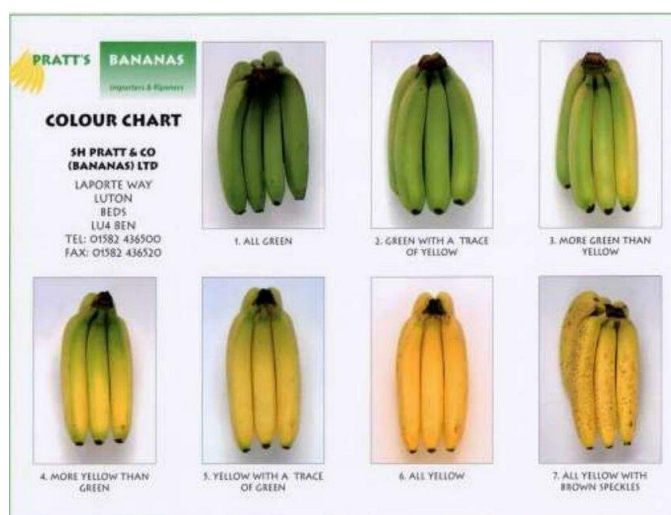


Figure 2.1: Standard Commercial Colour Chart for Ripening Stages Categorisation (Mathias et al., 2021)

It is crucial to address this post-harvest loss by utilizing rejected bananas to enhance profitability and support sustainability. For instance, rejected unripe bananas are used to produce green banana flour after harvest, which is converted into a useful product that can positively impact the economy. Similarly, Falcomer et al. (2019) also mentioned that green banana derivatives like green banana flour have the potential to be further explored. As a result, this can reduce environmental damage while improving the nutritional quality of the product.

2.2.1 Nutritional Composition of Green Bananas

Green banana products are gaining popularity due to their rich nutritional profile and functional properties. They are a valuable source of dietary fibre, essential vitamins (C, B3, B6, B12, provitamin A, E), and minerals such as potassium, phosphorus, magnesium, and zinc. Additionally, green bananas contain bioactive compounds, including phenolic compounds and resistant starch, which contribute to various health benefits (Falcomer et al., 2019; Sumbe & Salve, 2024).

According to Ravi and Mustaffa (2013), green bananas contain up to 70% to 80% starch. Sarawong et al. (2014) also reported that banana flour is high in resistant starch (40.9%–58.5%) and dietary fibre (6.0%–15.5%). Similarly, Hana et al. (2019) highlighted that green banana flour contains significant amounts of total dietary fibre with resistant starch being a major contributor. Dietary fibre in green bananas includes both soluble fibres (pectin) and insoluble fibres (cellulose, lignin, resistant starch). Resistant starch can be further classified as RS1, RS2, RS3, RS4, and RS5 based on real-life digestion and related to physiological properties (Sajilata et al., 2006). Green bananas are rich in RS2, which can promote colon health. According to Amini et al. (2016), resistant starch can help prevent colorectal cancer through colonic fermentation. Resistant starch especially amylose, is fermented by beneficial gut bacteria, producing SCFAs such as acetate, propionate, and butyrate. SCFAs are beneficial metabolites that are important for gut health, such as reducing inflammation, strengthening the gut barrier, balancing gut microbiota and others.

Additionally, green bananas are also abundant in essential phytonutrients, including amines, carotenoids, flavonoids, and phenolic acids. These bioactive compounds exhibit strong antioxidant properties, helping to combat oxidative stress and reduce the risk of chronic diseases (Sumbe & Salve, 2024). Additionally, antioxidants in bananas may help to prevent lipid oxidation and rancidity, reducing the need for artificial preservatives (Pathak et al., 2017). Given their diverse nutritional and functional properties, green bananas hold great potential as a health-promoting food ingredient.

According to Falcomer et al. (2019), most of the health benefits are related to gastrointestinal diseases, insulin metabolism, weight control, and renal and liver complications associated with diabetes, with most of the studies involving green

banana flour. For instance, studies showed a reduction in body weight and an increase in insulin sensitivity with green banana flour consumption among type 2 diabetes adults. Dietary intake of green bananas helps in stabilizing glucose levels by slowing carbohydrate absorption, thus preventing sharp spikes in blood sugar after meals (Adedayo et al., 2016). Green bananas can also reduce cancer risk through their antioxidant activities and antiangiogenic effect (Dahham et al., 2015).

2.2.2 Applications of Green Bananas in Food Product Development

Previous research has shown that green bananas have been utilised in developing several novel food products. According to the research (Kumar et al., 2023), green banana flour, banana modified starch, and banana peel flour were used to partially replace semolina in the production of the pizza base. Results showed that the amount of ash and crude fibre in the prepared dough rose with the addition of green banana flour, banana modified starch, and banana peel flour. Furthermore, pizza bases made with banana-based composite flour showed a positive impact on nutritional profiles with a 19% to 27% reduction in calories. Another researcher, Awaeloh et al. (2025), developed a novel extruded snack by utilizing rice flour (*Oryza sativa*) and unripe banana flour (*Musa* ABB cv. *Kluai 'Namwa'*) as a gluten-free base. This snack not only offered a convenient and appealing method for delivering antioxidant benefits but also recorded high consumer acceptance, making it a promising functional food product.

Additionally, Thakaeng et al. (2021) utilised unripe Cavendish banana flour to partially substitute wheat flour in bread making. The physicochemical characteristics of banana flour are similar to those of wheat flour, with a higher concentration of certain components such as minerals, fibre, and bioactive compounds. Similarly, Kaur

et al. (2020) agreed that banana flour can be used as a functional ingredient in bread making, particularly for gluten-intolerant consumers because it does not contain gluten. Other than bread making, green banana flour is used to produce low-calorie gluten-free noodles (Yu et al., 2020) and pasta with improved nutritional value (Pereira et al., 2022).

Besides that, green banana flour is also used in food products such as slowly digestible cookies, high-fibre symbiotic bread, fermented milk, ice cream, and yoghurt formulation (Yangilar, 2015; Batista et al., 2017). In fermented milk, the addition of 1% to 3% green banana flour to milk can yield a product with enhanced flavour and aroma through the fermentation process. Besides that, according to Hana et al. (2019), incorporating green banana flour into meat products can increase the dietary fibre and reduce fat content, thus allowing the industry to have healthier alternatives in addition to combating food waste and promoting sustainability.

Banana flour is also a good substitute for wheat flour when preparing Frankfurt-style sausages. Salazar et al. (2021) incorporated unripe banana flour into the formulation of pork sausage. The formulated products achieved a noticeable reduction in energy (kcal/100g), along with reduced fat content and enriched fibre, resulting in healthier meat products. Additionally, the resistant starch present in banana flour possibly enhanced the sausage's moisture retention and improved the texture.

These studies showed that by transforming rejected food sources deemed unsuitable for sale into high-value commercial products, this approach not only substantially reduces food waste but also aligns with the principles of sustainability and feasibility. Additionally, this approach offers practical health benefits and economic viability, thereby enhancing its overall appeal and impact.

2.2.3 Preparation of Green Banana Flour

Since bananas are climacteric and spoil quickly, drying is necessary to prolong their shelf life. Converting bananas into flour improves storage potential due to its extended shelf life and can be easily incorporated into various foods (Haslinda et al., 2009). Additionally, banana flour preserves the nutritional value of fresh bananas while reducing post-harvest losses. The nutritional composition of the flour is affected by the drying method, source, type, and timing of the bananas. Green banana flour is easy to produce and has many benefits, including longer shelf life and more effective packaging that makes storage and transportation easier (Yani et al., 2013). It can be made from rejected unripe bananas after harvest, which are converted into a useful product that can positively impact the economy (Thakaeng et al., 2021).

Green banana flour production involves two main stages, which are making banana chips and flour (Yani et al., 2013; Sumbe & Salve, 2024). Fresh green bananas are first washed with tap or chlorinated water, followed by peeling and slicing. The banana slices are then soaked in 5% ascorbic acid (Sumbe & Salve, 2024) or 0.3% sodium metabisulphite for 5 min (Yani et al., 2013) to prevent enzymatic browning. Banana slices are dried overnight at 60°C and ground in a mixer grinder to form flour. The flour is sieved through an 80 mesh sieve and stored in an air-tight container. However, the bananas are steamed for 10 min first before peeling in research conducted by Yani et al. (2013).

2.3 White Oyster Mushroom (*Pleurotus ostreatus*)

Mushrooms are macro-fungi with a fleshy, spore-bearing fruiting body. Mushrooms are considered functional foods due to their health benefits beyond their nutritional value. Hence, many mushroom species are used not only for food preparation, but also as natural medicines in many countries. More than 14,000 types of mushrooms are present globally with around 3000 species being edible. Among all types of mushrooms, more than 200 categories belong to the oyster mushroom (Zięba et al., 2021). There are several oyster mushroom species which include *Agaricus bisporus*, *Pleurotus species*, *Lentinus edodes*, and *Volvariella species*. These are the most acceptable varieties among the cultivated mushrooms due to their health benefits and biochemical properties (Assemie & Abaya, 2022).

Pleurotus sp. are commonly referred to as oyster mushrooms. *Pleurotus ostreatus* or also known as white oyster mushroom, is one of the most common edible mushroom species cultivated globally. This is due to its ability to degrade a wide spectrum of substrates and can be cultivated simply and cheaply with high yield (Effiong et al., 2024). White oyster mushroom grows fast under a wide range of temperatures from 10°C to 30°C and pH 6 to pH 8, and demands only a few environmental controls. It also possesses high nutritional value and medicinal importance. Additionally, its fruiting body is seldom attacked by any pests or diseases (Lesa et al., 2022).

2.3.1 Nutritional Composition of White Oyster Mushroom (*Pleurotus ostreatus*)

White oyster mushroom is widely consumed and is valued for its culinary applications as well as health benefits. It is gaining popularity due to its nutritional benefits, such as being high in proteins, carbohydrates, minerals, vitamins, antioxidants, phytochemicals and low in fat. It has a carbohydrate content of 43.42% to 66.54% which indicates its potential as an energy source. Interestingly, lower carbohydrate content was reported in white oyster mushroom grown on 100% sawdust compared to those combined with other substances, regardless of their countries of origin. The crude fat content and ash content of the white oyster mushroom were reported to range from 1.21% to 1.75% and 4.12% to 10.10% respectively (Elkanah et al., 2022; Irshad et al., 2023; Effiong et al., 2024).

The protein content of white oyster mushroom in previous studies ranged from 17.06% to 25.15%. It is a good source of quality protein which supplies essential amino acids to the body (Irshad et al., 2023; Effiong et al., 2024). Hence, this makes the white oyster mushroom a suitable meat alternative to animal-based proteins, especially for vegetarians. Moreover, it also has the potential to replace red and processed meat, thus lowering the risk of developing cardiovascular diseases, cancers and other oxidative stress-related diseases (González et al., 2020).

The crude fibre content of white oyster mushroom in previous studies was reported to range from 7.43% to 23.63%. It can aid in bowel movement, digestion, excretion, and gut health due to its high crude fibre content. Additionally, it can serve as a prebiotic that can enhance the production of SCFAs, which help regulate inflammation, oxidative stress, signal transduction and boost antioxidant profiles (Irshad et al., 2023; Effiong et al., 2024).

White oyster mushroom can serve as a functional food due to its high nutritional value and medicinal properties. It is a potential source of bioactive compounds, such as polysaccharides, phenolic compounds, and flavonoids (Sreedharan et al., 2025). These bioactive compounds present in white oyster mushroom confer various therapeutic properties such as antioxidant, anti-inflammatory, anti-carcinogenic, anti-viral, anti-fungal, antibacterial, antidiabetic, anti-atherogenic, immunomodulatory, hypoglycaemic, hypocholesterolemia, and hepatoprotective (Lesa et al., 2022; Mishra et al., 2022). Its antioxidant role and free radical scavenging activity help combat oxidative stress, DNA damage, tumour formation and development, carcinogenesis, and cellular damage related to aging (Gąsecka et al., 2015).

White oyster mushroom is the best among the *Pleurotus species* for the prevention and treatment of atherosclerosis due to the presence of a large amount of anti-atherosclerotic agents such as ergothioneine, lovastatin, and chrysin (Abidin et al., 2016). Furthermore, beta-glucans are a group of naturally occurring polysaccharides found in the cell wall structure of the white oyster mushroom. Several studies reported that they have immunomodulatory and anti-inflammatory effects, and can act as an adjuvant in cancer immunotherapy (Han et al., 2020; Cerletti et al., 2021). Additionally, these polysaccharides can promote the immune response and increase the activity of macrophages and natural killer cells, thus improving the body's defence against cancer (Sreedharan et al., 2025).