# DEVELOPMENT OF STRUCTURALLY ENHANCED AIR-DRIED RICE FLOUR-SOY PROTEIN ISOLATE NOODLES

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# DEVELOPMENT OF STRUCTURALLY ENHANCED AIR-DRIED RICE FLOUR-SOY PROTEIN ISOLATE NOODLES

**by**

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## TABLE OF CONTENTS


**ACKNOWLEDGEMENT** .......... **ii**

**TABLE OF CONTENTS** .......... **iii**

**LIST OF TABLES** .......... **ix**

**LIST OF FIGURES** .......... **xi**

**LIST OF SYMBOLS** .......... **xiii**

**LIST OF ABBREVIATIONS** .......... **xiv**

**LIST OF APPENDICES** .......... **xv**

**ABSTRACT** .......... **xix**

**CHAPTER 1 INTRODUCTION** .......... **1**

1.1 Background and Rational .......... 1

1.2 Statement of Problems .......... 2

1.3 Hypothesis .......... 3

1.4 Research Objectives .......... 4

**CHAPTER 2 LITERATURE REVIEW** .......... **5**

2.1 Rice noodles .......... 5

2.2 Origin of Rice Noodles .......... 5

2.2.1 Types of Rice Noodles .......... 5

2.2.2 Effects of rice flour/starch on the structure of rice noodles .......... 7

2.3 Preparation of Rice Noodles .......... 9

2.3.1 Fresh Rice Noodles (Laksa) .......... 9

2.3.2 Flat Rice Noodles (*Kuay Teow)* .......... 11

2.3.3 Dried Rice Noodles .......... 11

2.3.4 Instant Rice Noodles .......... 13

2.4 Quality of Rice noodles .......... 14

2.4.1 The texture of rice noodles .......... 14

2.4.2 Cooking quality of rice noodles .................................................. 15

2.4.3 Sensory properties of rice noodles ............................................... 17

2.5 Critical physico-chemical processes that affect the quality of rice noodles... 18

2.5.1 Gelatinization ..................................................................... 18

2.5.2 Retrogradation ..................................................................... 18

2.6 Different technologies employed to enhance the quality of rice noodles. ..... 19

2.6.1 Aging of rice grains ................................................................ 19

2.6.2 Fermentation of rice grains ....................................................... 20

2.6.3 Use of hydrocolloids and other additives. ..................................... 21

2.6.4 Hydrothermal treatment of rice flours and starches ........................ 23

2.7 Soy protein isolate (SPI) and its functional properties. .................................. 24

2.7.1 Production of soy proteins ........................................................ 25

2.7.2 Nutritional and health benefits of soy proteins ............................. 28

2.7.3 Functional properties of soy proteins. .......................................... 29

2.8 Gelation in food systems. ............................................................................ 30

2.8.1 Protein gels .......................................................................... 31

2.8.2 Types of protein gels. ............................................................. 31

2.8.3 Factors affecting protein gel formation. ....................................... 32

2.8.4 Gelation of soy proteins ........................................................... 33

2.8.5 Glucono-δ-lactone (GDL) in gelation of soy proteins ....................... 34

2.9 The use of MTG in food research and processing .......................................... 35

2.9.1 The Use of MTG in noodles and pasta .......................................... 38

2.10 Superheated steam in food processing. ......................................................... 40

2.11 The use of Response Surface methodology (RSM) in Food systems. ........... 41

2.11.1 RSM theorem, procedure and Design of Experiments. ..................... 42

2.11.2 Applications of RSM in Food processes. ...................................... 44

**CHAPTER 3 EFFECTS OF COMBINED TREATMENTS OF MTG AND GDL ON THE COOKING, TEXTURAL AND MECHANICAL PROPERTIES OF FRESH RICE FLOUR - SOY PROTEIN ISOLATE NOODLES................ 46**

3.1 Introduction ........................................................................................ 46

3.2 Materials and Methods ........................................................................ 49

3.2.1 Materials.......................................................................................... 49

3.2.2 Proximate composition the of commercial rice flour..................... 49

3.2.3 Determination of the amylose content of the commercial rice flour ......................................................................................................... 49

3.2.4 Preparation of rice noodles............................................................. 50

3.2.5 Protein electrophoretic pattern ....................................................... 51

3.2.6 pH measurements and cooking properties ..................................... 52

3.2.7 Colour analysis................................................................................ 53

3.2.8 Texture profile analysis.................................................................. 53

3.2.9 Tensile strength .............................................................................. 54

3.2.10 Structural breakdown analysis ...................................................... 55

3.2.11 Microstructure ................................................................................ 56

3.2.12 Statistical analysis ......................................................................... 56

3.3 Results and discussion........................................................................... 56

3.3.1 SDS-PAGE analysis.......................................................................... 57

3.3.2 pH values and cooking parameters of cooked noodles .................. 58

3.3.3 Colour characteristics of cooked noodles...................................... 59

3.3.4 Textural and mechanical properties of cooked noodles ................. 60

3.3.5 Structural breakdown analysis of cooked noodles ......................... 63

3.3.6 The microstructure of cooked noodles........................................... 65

3.4 Conclusion............................................................................................. 67

**CHAPTER 4 OPTIMIZATION OF SOY PROTEIN ISOLATE, MICROBIAL TRANSGLUTAMINASE, AND GLUCONO-Δ-LACTONE IN RICE FLOUR – SOY PROTEIN NOODLES. ..... 68**

4.1 Introduction ..... 68

4.2 Materials and methods. ..... 70

4.2.1 Materials ..... 70

4.2.2 Experimental design ..... 70

4.2.3 Preparation of rice noodles ..... 71

4.2.4 Texture profile analysis ..... 74

4.2.5 Tensile strength determination ..... 74

4.2.6 Cooking time determination ..... 74

4.2.7 Data analysis ..... 74

4.2.8 Numerical optimization ..... 74

4.2.9 Sensory evaluation of the noodles ..... 75

4.2.10 Microstructure and pH value of the cooked noodles used for sensory evaluation. ..... 76

4.3 Results and discussion ..... 76

4.3.1 Diagnostic verification of the models. ..... 76

4.3.2 Response surface plotting and the effects of the independent variables on the response factors of the noodles. ..... 78

4.3.3 Numerical optimization ..... 83

4.3.4 Validation of optimal parameters ..... 85

4.3.5 Sensory Evaluation ..... 86

4.3.6 Microstructure of cooked noodles ..... 87

4.4 Conclusion ..... 89

**CHAPTER 5 EVALUATION OF AIR-DRIED SOY PROTEIN ISOLATE-RICE NOODLES PREPARED VIA COMBINED TREATMENT WITH MICROBIAL TRANSGLUTAMINASE AND GLUCONO-δ-LACTONE. ..... 91**

5.1 Introduction ..... 91

5.2 Materials and Methods ..... 94

5.2.1 Materials ........ 94
5.2.2 Preparation of Air-dried rice noodles ........ 94
5.2.3 pH and cooking properties of the air-dried noodles ........ 96
5.2.4 Colour analysis of air-dried rice noodles ........ 96
5.2.5 Textural profile analysis of air-dried rice noodles ........ 96
5.2.6 Tensile strength of air-dried rice noodles ........ 97
5.2.7 Fourier Infrared Spectrometer (FTIR) ........ 97
5.2.8 Thermal properties of the noodles ........ 97
5.2.9 Microstructural properties of the noodles ........ 98
5.2.10 Statistical analysis ........ 98
5.3 Results and Discussion ........ 98
5.3.1 pH, cooking, and colour properties of cooked noodles ........ 98
5.3.2 Textural properties of the cooked noodles ........ 101
5.3.3 Thermal properties of the noodles ........ 103
5.3.4 FTIR analysis of the noodles ........ 105
5.3.5 Structural morphology of the noodles ........ 108
5.4 Conclusion ........ 109

**CHAPTER 6 EVALUATION OF RICE FLOUR-SOY PROTEIN ISOLATE NOODLES STABILIZED WITH MICROBIAL TRANSGLUTAMINASE AND GLUCONO-δ-LACTONE AND DRIED USING SUPERHEATED STEAM . 111**

6.1 Introduction ........ 111
6.2 Materials and Methods ........ 113
6.2.1 Materials ........ 113
6.2.2 Preparation of SHS-dehydrated rice noodles ........ 114
6.2.3 Cooking properties and pH values of the SHS-dehydrated noodles ........ 115
6.2.4 Colour Analysis of cooked SHS-dehydrated noodles. ........ 115
6.2.5 Texture Profile Analysis of cooked noodles. ........ 116

6.2.6 Fourier Infrared Spectrometer (FTIR) ........ 116
6.2.7 Thermal properties of the cooked noodles ........ 116
6.2.8 Microstructure ........ 116
6.2.9 Statistical analysis ........ 116
6.3 Results and Discussions ........ 116
6.3.1 General description of the cooked noodles. ........ 116
6.3.2 pH, colour, and cooking properties of the noodles. ........ 117
6.3.3 Textural properties of the noodles. ........ 120
6.3.4 Thermal properties of the noodles. ........ 121
6.3.5 FTIR spectra of the noodles. ........ 123
6.3.6 Microstructure of the noodles. ........ 125
6.4 Conclusion ........ 126
**CHAPTER 7 ........ 128**
7.1 Conclusion ........ 128
7.2 Recommendations for Future Research ........ 129
**REFERENCES ........ 130**
**APPENDICES**
**LIST OF PUBLICATIONS**

# LIST OF TABLES


**Page**

Table 2.1 Types of Rice noodles in Asian markets ........ 6

Table 2.2 Effect of MTG applications in the food industry. ........ 38

Table 2.3 Effect of MTG on different quality parameters of rice noodles ........ 39

Table 3.1 Formulation and designation of noodles ........ 50

Table 3.2 pH and cooking parameters of noodles ........ 58

Table 3.3 Colour values of cooked noodles ........ 60

Table 3.4 Textural parameters of cooked noodles ........ 61

Table 3.5 Structural breakdown analysis (Multiple extrusion cells) of cooked noodles ........ 64

Table 4.1 Different levels of the independent variables ........ 73

Table 4.2 Regression analysis of 2nd order polynomial models for various responses. ........ 77

Table 4.3 Numerical optimization solutions ........ 84

Table 4.4 Numerical optimization of processing variables ........ 85

Table 4.5 Optimum conditions, experimental and predicted value of response at optimized conditions ........ 86

Table 4.6 pH and sensory evaluation of the rice noodle samples. ........ 87

Table 5.1 Designation and composition of rice noodle samples. ........ 96

Table 5.2 pH, cooking, and colour properties of the noodles. ........ 99

Table 5.3 Textural and mechanical properties of the cooked noodles. ........ 101

Table 5.4 Thermal properties of the cooked noodles ........ 104

Table 5.5 Thermal properties of the cooked noodles ........ 107

Table 6.1 Designation, formulation, composition, and description of noodles ........ 115

Table 6.2 pH, cooking, and colour properties of the noodles. .......................... 118

Table 6.3 Textural properties of the noodles.................................................... 120

Table 6.4 Thermal properties of the noodles.................................................... 122

Table 6.5 Molecular ordering ($R_{(1022/1047)}$) of the starches in the noodles ....... 124

## LIST OF FIGURES

**Page**

Figure 2.1 Preparation of fresh rice noodles (Lubowa *et al.*, 2018). 10

Figure 2.2 Preparation of dried rice noodles 12

Figure 2.3 Preparation of instant rice noodles (Toh, 1998) 14

Figure 2.4 Preparation of defatted soy flour (Johnson *et al.*, 2015) 26

Figure 2.5 Process flow chart for the production of soy protein concentrate (Thrane *et al.*, 2017) 27

. Figure 2.6 Process flow chart for soy protein isolate (SPI) production (Thrane *et al.*, 2017). 28

Figure 2.7 Protein gelation mechanism (Alting *et al.*, 2003). 34

Figure 2.8 Hydrolysis of GDL (Campbell *et al.*, 2009). 34

Figure 2.9 Crosslinking action of MTG (Han *et al.*, 2019). 36

Figure 2.10 Basic Superheated system (Ezhil, 2010). 41

Figure 3.1 Sample preparation. 51

Figure 3.2 SDS-PAGE analysis of protein fractions extracted from fresh rice noodles samples. 57

Figure 3.3 Tensile strength and elasticity modulus of cooked noodles samples 62

Figure 3.4 Representative graph for the breakdown of fresh rice noodles samples 63

Figure 3.5 Scanning electron micrographs of cooked noodles samples: A= RN, B= RNS-GDL, C = RNS-MTG, D =RNS-COM (300x magnification) 66

Figure 4.1 Preparation of rice flour- soy protein isolate noodles. 72

Figure 4.2 3D response surface diagram showing the significant effect of SPI, GDL, and MTG on the hardness of the noodles. 78

Figure 4.3 3D response surface diagram showing the significant effect of SPI, GDL, and MTG on the springiness of the noodles. ........................... 79

Figure 4.4 3D response surface diagram showing the significant effect of SPI, GDL, and MTG on the chewiness of the noodles. ............................ 80

Figure 4.5 3D response surface diagram showing the significant effect of SPI, GDL, and MTG on the tensile strength of the noodles. ..................... 81

Figure 4.6 3D response surface diagram showing the significant effect of SPI, GDL, and MTG on the tensile strength of the noodles. ..................... 82

Figure 4.7 The microstructures of selected rice noodle formulations used for sensory evaluation. (A = RN, B = RNS-COM1, C = RNS-COM 2, D = RNS-COM 3.) (300x magnification) ......................................... 88

Figure 5.1 Preparation of air-dried restructured SPI-rice noodles...................... 95

Figure 5.2 FTIR spectra of the cooked air-dried noodles (A=RNS-COM1, B=RNS-COM2, C=RNS-COM3, D=ADRN, E=ADRN-S5, F=ADRN-S10, G=RNS-COM1-S5, H=RNS-COM1-S10) ............. 106

Figure 5.3 Scanning electron micrographs of the cooked air-dried noodles (A=RNS-COM1, B=RNS-COM2, C=RNS-COM3, D=ADRN, E=ADRN-S5, F=ADRN-S10, G=RNS-COM1-S5, H=RNS-COM1-S10)......................................................................... 108

Figure 6.1 Picture of the noodles (A=RN-S10 B=RN-SHS, C=RNS-COM-S10, D =RNS-COM-SHS). ............................................................ 117

Figure 6.2 FTIR Spectra of the noodles. ......................................................... 123

Figure 6.3 Scanning electron morphology of the noodles (A=RN-S10 B=RN-SHS, C=RNS-COM-S10, D =RNS-COM-SHS) (300x magnification). ................................................................... 126

# LIST OF SYMBOLS

| | |
|---|---|
| g | Grams |
| h | Hours |
| kDa | Kilodaltons |
| kg | Kilograms |
| kpa | Kilo pascal |
| m | Metres |
| min | minutes |
| mm | Millimetres |
| N | Newton |
| s | Seconds |

## LIST OF ABBREVIATIONS

| | |
|---|---|
| ADRN | Air-dried rice noodles |
| ANOVA | Analysis of variance |
| CCD | Central composite design |
| CI | Composite interval |
| DMSO | Dimethyl sulfoxide |
| DSC | Differential scanning calorimeter |
| FTIR | Fourier Transform Infrared spectroscopy |
| GDL | Glucono-δ-lactone |
| MEC | Multiple extrusion cycle |
| MTG | Microbial transglutaminase |
| RN | Rice flour noodles |
| RNS | Rice flour- soy protein isolate noodles |
| RNS-COM | Rice flour-soy protein isolate noodles with MTG and GDL |
| RNS-GDL | Rice flour-soy protein isolate noodles with GDL |
| RNS-MTG | Rice flour-soy protein isolate noodles with MTG |
| RSM | Response surface methodology |
| SDS-PAGE | Sodium dodecyl sulphate polyacrylamide gel electrophoresis |
| SEM | Scanning electron microscope |
| SHS | Super-heated steam |
| SPI | Soy protein isolate |
| SPSS | Statistical package for social sciences |
| TPA | Texture profile analyser |
| XG | Xanthan gum |
| YAN | Yellow alkaline noodles |

# LIST OF APPENDICES

Appendix A Human research ethics committee (USM) approval letter.

**PEMBANGUNAN MI TEPUNG BERAS-ISOLAT PROTEIN SOYA TERKERING UDARA DENGAN STRUKTUR DIPERTINGKATKAN.**

## ABSTRAK

Mi beras adalah bebas gluten dan mempunyai kandungan nutrisi yang sangat baik, namun disebabkan sifat berfungsinya yang lemah dalam pembentukan doh visco-elastik berterusan telah menyumbang kepada tekstur mi beras yang lemah. Mi beras segar mempunyai jangka hayat yang pendek dan terdedah kepada kerosakan kerana kandungan lembapan yang tinggi. Walau bagaimanapun, mi beras terkering-udara dilaporkan mengalami pengecutan semasa diproses dan mempunyai ciri-ciri rehidrasi yang lemah. Penyelidikan ini bertujuan untuk membangunkan mi beras-isolat protein soya. Pertama sekali, mi beras segar-protein soya isolat (RNS) telah dihasilkan bagi menyamai mi kuning (YAN) dengan menggabungkan transglutaminase mikrob (RNS-MTG), glucono-δ-lakton (RNS-GDL), dan kedua-dua MTG dan GDL ke dalam mi RNS (RNS-COM). Seterusnya, kaedah rangsangan permukaan (RSM), reka bentuk pusat (CCD) digunakan untuk mengoptimumkan penambahan protein soya isolat (SPI), mikrob transglutaminase (MTG), dan glucono-δ-lactone (GDL), diikuti oleh penilaian deria. Ini diikuti dengan mengkaji kesan pengukusan selama 5 (S5) atau 10 (S10) min semasa penyediaan RNS-COM-S5 dan RNS-COM-S10 terkering udara. Seterusnya, RNS-COM dikeringkan menggunakan wap panas lampau (SHS) untuk menghasilkan RNS-COM-SHS. Pembentukan ikatan γ-glutamyl-lysine dalam RNS-COM dan RNS-MTG telah ditunjukkan oleh analisis gel elektroforesis (SDS-PAGE). Mikroskop Elektron Pengimbas menunjukkan bahawa berbanding dengan yang lain, struktur RNS-COM adalah lebih padat, lebih lancar dan mempunyai saling hubungan agregat yang jelas di antara agregat. Masa memasak optimum adalah mengikut urutan:

YAN > RNS-COM > RNS-MTG, RNS-GDL > RN (mi beras), kekuatan tegangan adalah mengikut urutan; YAN > RNS-COM > RNS-MTG > RNS-GDL> RN dan keanjalan berada dalam susunan; YAN > RNS-COM > RNS-MTG, RNS-GDL > RN. Secara keseluruhan, RNS-COM menunjukkan parameter pemecahan tekstur dan struktur yang serupa berbanding dengan YAN. Perubahan dalam struktur mikro dan RNS-COM yang dipertingkatkan dalam sifat-sifat tertentu berkemungkinan disebabkan oleh pertautan silang protein yang dipertingkat akibat penggelan sejuk protein yang dirangsangkan oleh MTG dan GDL pada nilai pH yang direndahkan. Angka-angka optimum menunjukkan bahawa RNS-COM1 yang disediakan dengan SPI, 68.32 (g/Kg tepung beras), MTG, 5.06 (g/Kg tepung beras) dan GDL, 5.0 (g/Kg tepung beras) memberikan tindak balas pembolehubah yang terbaik; kekerasan (53.19N), keanjalan (0.76), kekenyalan (20.28N), kekuatan ketegangan (60.35kPa), dan masa memasak (5.15 min). RNS-COM1 mempunyai mikrostruktur yang lebih padat dengan rongga yang kurang, dan mendapat penerimaan sensori keseluruhan yang tertinggi untuk formulasi yang dioptimumkan (RNS-COM1) berbanding dengan sampel lain. RNS-COM-S5 dan RNS-COM-S10 menunjukkan pengurangan dalam masa memasak (5.35 min), kehilangan semasa memasak (7.11%) dan peningkatan hasil memasak (125 %), yang kemungkinan disebabkan entalpi gelatinisasi yang rendah, di samping pengekalan sifat tekstur dan mekanikal yang lebih tinggi dan signifikan ($P < 0.05$) daripada kawalan. Secara amnya, ciri-ciri tekstur dan microstruktur menunjukan tekstur dan rangkaian yang lebih teguh dalam RNS-COM-SHS dan RNS-COM-S10 berbanding sampel lain. Masa memasak optimum ($P < 0.05$) adalah mengikut urutan; RN-SHS, RNS-COM-SHS < RN-S10 < RNS-COM-S10. Hasil daripada rawatan gabungan (COM) dan pengeringan SHS, mi RNS-SHS boleh di masak selama 6 min, di mana ada pengurangan ketara daripada 7 min yang diperlukan untuk memasak RNS-COM1-S10. Kesimpulannya, gabungan MTG dan GDL boleh menghasilkan mi beras -protein soya isolat terkering udara dengan struktur yang lebih teguh serta sifat tekstur, masa memasak dan sifat mekanikal yang dipertingkatkan.

## DEVELOPMENT OF STRUCTURALLY ENHANCED AIR-DRIED RICE FLOUR-SOY PROTEIN ISOLATE NOODLES

### ABSTRACT

Rice flour noodle is gluten-free, with excellent nutritional properties, but the lack of the functionality of forming a continuous visco-elastic dough contributes to rice flour noodles' poor texture. Fresh rice noodles have a short shelf life and are prone to spoilage due to high moisture content. However, air-dried rice noodles have been reported to shrink while processed and have poor rehydration characteristics. This research aimed to develop a structurally enhanced air-dried rice flour-soy protein isolate noodle. Firstly, fresh rice flour-soy protein isolate noodles (RNS) were developed to match those of yellow alkaline noodles (YAN) by incorporating microbial transglutaminase (RNS-MTG), glucono-δ- lactone (RNS-GDL), and both MTG and GDL into the RNS noodles (RNS-COM). After that, the central composite design of response surface methodology was employed to optimize the inclusion of soy protein isolate (SPI), microbial transglutaminase (MTG), and glucono-δ-lactone (GDL), after which sensory evaluation was carried out. This was followed by investigating the effects of steaming for 5 (S5) or 10 (S 10) min during the preparation of air-dried RNS-COM-S5 and RNS-COM-S10, respectively. Next, RNS-COM was dried using superheated steam (SHS) to yield RNS-COM-SHS. The formation of $\gamma$-glutamyl-lysine bonds in RNS-COM and RNS-MTG was shown by Sodium Dodecyl Sulphate Polyacrylamide Gel Electrophoresis analysis. Scanning Electron Microscope showed that compared to others, the structure of RNS-COM was denser, smoother with extensive apparent interconnectivity of aggregates. The optimum cooking time was in the order: YAN>RNS-COM>RNS-MTG, RNS-GDL> RN (rice flour noodles), tensile strength was in the order; YAN > RNS-COM > RNS-MTG > RNS-GDL> RN and elasticity were in the order; YAN > RNS-COM > RNS-MTG, RNS-GDL > RN. Overall, RNS-COM showed similar textural and structural breakdown parameters compared to YAN's. Changes in microstructures and improved RNS-COM in certain properties were likely due to enhanced crosslinking of proteins attributed to MTG and GDL-induced cold gelation of proteins at reduced pH value. Numerical optimization showed that RNS-COM1 prepared with SPI,68.32(g/Kg of rice flour), MTG,5.06 g/Kg of rice flour) and GDL, 5.0 (g/Kg of rice flour) gave the best response variables; hardness (53.19N), springiness (0.76), chewiness (20.28N), tensile strength (60.35kPa), and cooking time (5.15 min). RNS-COM1 had a more compact microstructure with fewer hollows, and overall sensory panelists also showed the highest preference for the optimized formulation (RNS-COM1) compared to other samples. RNS-COM-S5 and RNS-COM-S10 showed a reduction in cooking time (5.35 min) and cooking loss (7.11 %) and increased cooking yield (125 %), supposedly due to low gelatinization enthalpy, while retaining textural and mechanical properties, significantly higher ($P < 0.05$) than the controls. In general, textural and microstructural properties data indicated higher textural properties and a more robust network in RNS-COM-SHS and RNS-COM-S10 than other noodles. However, optimum cooking time ($P < 0.5$) was in the order; RN-SHS, RNS-COM-SHS < RN-S10 < RNS-COM-S10. As a result of the COM treatment and SHS-drying, RNS-SHS could cook for 6 min, which a significant reduction from 7 min required to cook RNS-COM1-S10. Conclusively, it is possible to use the combination of MTG and GDL to develop structurally enhanced air-dried rice flour-soy protein isolate noodles with improved the textural, cooking, and mechanical properties

# CHAPTER 1

# INTRODUCTION

## 1.1 Background and Rational

Rice noodles are the major processed food made from rice, convenient to prepare and meet modern lifestyles (Lu & Collado, 2019), which benefits both consumers and manufacturers. Rice noodles have assumed staple food status globally, especially in Asian countries. Rice noodles are the second main rice product consumed in Asia (Fu, 2008). In addition to being served in between meals or served as a main dish, thus increasing market potential, laksa, an iconic dish in Peranakan cuisine has an addictive and ubiquitous taste (Duruz, 2011). Laksa can be found in Malaysia, Singapore, Indonesia, and southern Thailand.

Rice noodles can be fresh, dried, and instant rice noodles. Fresh rice noodles are homemade or produced on a small scale because of their short shelf life. Instant and dried rice noodles have a stable shelf life and are widely available in stores. Frozen noodles are not widespread, although seen in some supermarkets, because they are regarded as premium products (Li *et al.*, 2021). Rice noodles can be prepared by extrusion or batter sheeting. However, the technology for processing rice-based noodles is straightforward, which entails soaking rice and then milling, followed by cooking and kneading it into a dough, extruding into threads, or slicing it into strips.

Rice is the principal ingredient for the preparation of rice flour noodles because it has no known allergens. Rice’s embryo and aleurone layer are both easily digestible and nutritious, including some amounts of dietary fibre, vitamins, minerals, and antioxidants. (Sen *et al.*, 2020). Even though rice has low proteins compared to other cereals, it does not contain gluten responsible for celiac diseases. Presently, the only way to combat the disease is to avoid gluten-containing foods. (Cenit *et al.*, 2015).

Rice flour noodle is gluten-free, with excellent nutritional properties, and thus, have become a preferred type of noodle for people susceptible to celiac disease. However, the absence of gluten in rice flour is responsible for the lack of functionality to form a continuous visco-elastic dough, contributing to the poor texture of rice flour noodles (Kang *et al.*, 2018).

## 1.2 Statement of Problems

The demand for gluten-free noodles has risen due to the increasing population of people (over 80 million) susceptible to celiac disease (Ashtari *et al.*, 2021), a common food intolerance triggered by consuming foods prepared from wheat, barley, and rye. There have been attempts to prepare gluten-free noodles from tiger nut flour and mung bean, combined with certain hydrocolloids. Even though the potential is good, tiger nut flour may not be as acceptable or as popular as rice flour as a noodle's ingredient in many parts of the world. Rice flour is locally sourced unlike wheat that is majorly imported, gluten-free, with excellent nutritional properties. However, the absence of gluten in rice flour is responsible for the lack of the functionality of forming a continuous visco-elastic dough, contributing to the poor texture of rice flour noodles. The textural quality of cooked rice noodles is the most important property that influences consumers' overall acceptability. High cooking loss, weak cooking tolerance, and sticky mouthfeel are the main quality issues with rice noodles.

Some of the existing technologies deployed to enhance the texture of rice noodles, such as fermentation, use of whey proteins, Hydrothermal treatments, use of high amylose maize starch and others, are not sustainable nor commercially available due to the cost of proteins and other materials and concerns for the energy requirements. Fresh rice noodles have a short shelf life and are prone to spoilage due to high moisture content. More so, fresh noodles are susceptible to discolouration, which, of course, is undesirable. Therefore, reducing the moisture content will extend shelf life and preserve the flavour and taste, positively affecting the noodles' market value. However, air-dried rice noodles shrink while being processed and have poor rehydration characteristics attributed to their less porous structure, developing tough texture, and suffered from long cooking times.

## 1.3 Hypothesis

It was hypothesized that incorporating soy protein isolate (SPI), microbial transglutaminase (MTG), and glucono-δ-lactone (GDL) into the rice noodle formulation would trigger the formation of covalent bonding, electrostatic, and hydrophobic interactions, thereby imparting structural integrity in the rice noodle and yielding fresh rice noodles with improved textural and cooking properties. Cold gelation could be achieved by introducing an acidulant such as GDL that releases gluconic acid slowly into the system to promote gelation of thermally aggregated protein molecules. Furthermore, during cooling, more interactions between proteins could occur via a process known as cold gelation.

While some researchers have employed several technologies to improve the texture of rice noodles, there has been no attempt to combine SPI, MTG, and GDL in rice noodles. Furthermore, it was thought that the determination of the optimum inclusion of SPI, MTG and GDL would yield noodles with desirable texture and structure, acceptable by the consumers.

It was also presumed that pre-drying steaming treatments would enhance the rehydration characteristics of air-dried structurally enhanced rice noodles. In contrast, superheated steam would facilitate faster starch gelatinization, ultimately producing dried noodles that would cook faster while maintaining improved texture and structure.

## 1.4 Research Objectives

The main objective of this research is to develop structurally enhanced air-dried rice flour-soy protein isolate noodles (RNS). To achieve this, the specific objectives include.

1. To impart structural improvement on fresh rice noodles using low levels of SPI with GDL & MTG to form gels within the fresh rice noodles (FRN)
2. To determine the optimum levels of inclusion of SPI, MTG & GDL in producing high quality & acceptable restructured Rice noodles, using RSM
3. To improve the handling, textural, & physical properties, structural morphology, cooking & eating qualities of the modified air-dried rice noodles by steaming
4. To enhance the rehydration characteristics of restructured dried rice noodles using super-heated steam.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Rice noodles

This chapter reviews the origin, types, and methods of rice noodles preparations. The various quality parameters of rice noodles and the processes influencing them were also highlighted. Furthermore, the existing technologies employed to improve the texture and structure of rice noodles were also analysed. The impact of protein crosslinking in food processing operations and the use of superheated steam were also discussed.

## 2.2 Origin of Rice Noodles

Rice noodles originated in China and have assumed staple food status in Southeast Asian countries like Thailand, Singapore, and Malaysia. Rice noodles are the second main rice product consumed in Asia (Fu, 2008). Noodles are primarily processed food made from rice. They are convenient to prepare and meet modern lifestyles, which benefits both consumers and manufacturers.

### 2.2.1 Types of Rice Noodles

Today, rice noodles are produced in Malaysia, Korea, Japan, and many other countries. They come in different shapes and sizes and are called different names (Table 2.1)

Rice noodles come in different forms, such as instant rice noodles, fresh and dried rice noodles. Instant (noodles that are steamed and fried with oil) and dried rice noodles have a stable shelf life and are widely available in stores (Lu & Collado, 2018).

Rice noodles can be prepared in different places, mainly by extrusion or batter sheeting. However, the technology for processing rice-based noodles is straightforward, requiring soaking Rice and then milling. The milled rice flour is mixed with water and kneaded into a dough, extruded into threads, or sliced into strips. Rice noodles can be consumed fresh or dried for extended shelf life (Ahmed *et al.*, 2016)

Noodles can be prepared by frying and combined with other condiments like meats and vegetables or boiled to make a noodle soup (Supakornchuwong & Suwannaporn, 2012).

Table 2.1 Types of Rice noodles in Asian markets

| Rice noodles | Other names | Physical features |
|---|---|---|
|  Rice Vermicelli | *Bihun* (Malay), *mifen* (Chinese), *sen mee* (Thai) | Round and very thin with a length of about 18 inches. |
|  Rice stick noodles | *Pad thai* (Thai), *bahn pho* (Vietnam) | Flat, straight, and has about 12 cm in length |
|  Kuay Teow | *Shahe fun*, *ho fun* (Chinese) | About 2 cm wide, flat, and very bright in colour |
|  Lai fun/ Laksa noodles | *Laksa* (Malaysia), *banh canh* (Vietnam) | 6-8 inches long, springy, and firm |

| | | |
|---|---|---|
|  Silver Needle noodles | *Lau shu fun* (China) | Pointed tips on each end,2 inches long, short, and quarter-inch wide |

### 2.2.2 Effects of rice flour/starch on the structure of rice noodles

Rice flour is the primary raw material for rice noodle processing. Rice flour contains about 78% carbohydrates, 0.4–0.8% fat, and 7% protein (Leewatchararongjaroen & Anuntagool, 2016). Rice flour also contains a good measure of B vitamins; thiamin, niacin, and riboflavin (Fresco, 2005). Therefore, the structure of rice noodles depends considerably on the rice starch properties. Rice flour is very suitable to make gluten-free noodles, bread, cakes, and many more. Rice noodles serve as an excellent substitute for wheat noodles.

Milling brown or white rice grains produces rice flour. The rice noodles' quality is affected by rice flour's physicochemical and rheological properties produced from various rice grains (Fari *et al.*, 2011; Hormdok & Noomhorm, 2007). Furthermore, the rice flour particle sizes can, as well, influence the noodles' quality (Hormdok & Noomhorm, 2007; Nura *et al.*, 2011). Noodles made from smaller particle-sized flours have better textural characteristics.

Rice starch is easily digestible and has a wide distribution of granule size. Some researchers believe the sticky nature of rice noodles is caused by the leaching of small molecular starch fractions during cooking, which could be mitigated by the inclusion of monoglyceride and modified starch in a rice flour noodle system. The complex formation led to the reduction of the starch water-retention capacity, which minimized the stickiness and cooking yield of the noodles (Low *et al.*, 2019).

When heat is applied to a rice starch with water, leaching of the amylose and swelling of the starch granules occurs, which leads to starch gelatinization. The swollen granules will eventually burst and let out all the amylose and amylopectin and form a gel.. The quality and strength of the rice noodles formed are dependent on the amylose-amylopectin ratio of the rice starch, which is influenced by the rice variety and methods of starch processing (Tan *et al.*, 2009). Due to the high amylose content of Indica rice, it is preferred for making rice noodles. The amylose component of rice starch enhances rice noodles' viscoelastic properties, while amylopectin softens the noodles.

The flour's proximate and starch composition properties would help understand its possible uses (Zhang *et al.*, 2007). The maximum protein content is 8.16%, while the fat content is 0.07% for brown Rice. Rice flour is considered as having high amylose if it has 25-33% amylose, intermediate amylose rice flour has about 20-25% amylose, while rice flour with 12-20% amylose is classified as low amylose and very low amylose rice flour contains 2-12% amylose, and waxy Rice contains (1-2% amylose content. Rice noodles are best made from rice flour with a massive amount of amylose, high gel consistency, and low starch gelatinization (Yoenyongbuddhagal & Noomhorm, 2002). Noodles with a soft texture are prepared from rice flour with an intermediate amylose concentration. Such noodles have a high cooking loss. Rice flours that are very low in amylose concentration are not suitable for preparing noodles (Qazi *et al.*, 2014). The rice variety, amylose/amylopectin concentration, and aging duration determine rice starch's gelling properties (Pitiphunpong & Suwannaporn, 2009). Hydrothermal treatment of flour enhances the organoleptic properties of rice noodles (Hormdok & Noomhorm, 2007). Rice flour and starch enormously impact the textural quality of rice noodles. The starch’s paste viscosities, and swelling power influence rice noodles’ quality. Rice flour with high amylose concentration yields bright coloured noodles with reduced swelling power (Qazi *et al.*, 2011).

## 2.3 Preparation of Rice Noodles

Ordinarily, noodles' preparation involves mixing dough, sheeting, reducing sheet thickness, and developing noodles strands. The noodles may be made in diverse forms. After that, the noodles may be sold at the shops fresh or dried, to extend its shelflife (Fu, 2008).

### 2.3.1 Fresh Rice Noodles (Laksa)

Fresh rice flour noodles are prepared by mixing rice flour with water to form a dough molded and cut into desired shapes or extruded, cooked, and cooled (Figure. 2.1) (Lubowa *et al.*, 2018). Fresh rice noodles are prepared using rice flour produced from long-grain Indica rice. The rice flour is made by cleaning and soaking the rice grains before milling. Usually, the rice grains are aged for about 9-12 months. Soaking of the aged rice grains often leads to the fermentation of the grains and the proliferation of some lactic acid bacteria, reducing the pH of the suspension from pH 7 to pH 4. Due to the absence of gluten in rice flour, the starch slurry's dough will be weak. This debacle can be remedied by partially gelatinizing the starch through the processing of steaming, during which some amylose component of the rice starch is freed, and the amylopectin molecules will then hold other components of the starch during the mixing process (Yalcin & Basman, 2008).

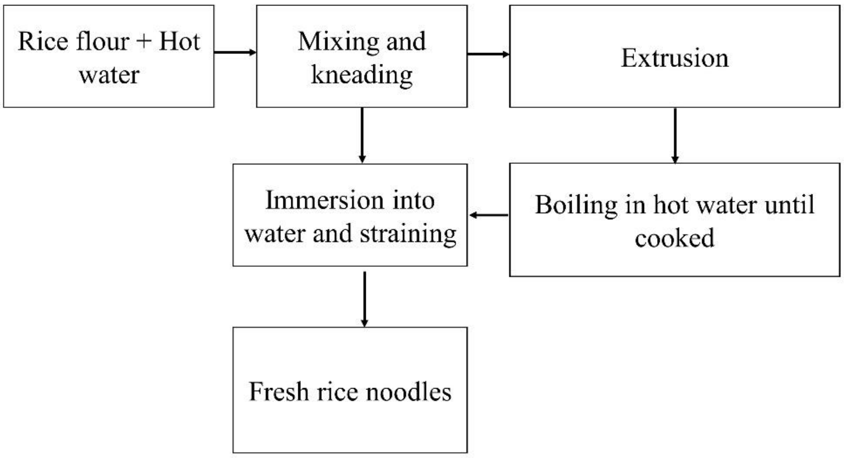


Figure 2.1 Preparation of fresh rice noodles (Lubowa *et al.*, 2018).

Some producers substitute some rice flour with corn and tapioca starches to make fresh rice noodles with improved texture and appearance. The presence of the tapioca starch lowers the pasting temperature and increases high peak viscosity, which provides the much-needed improved structure during subsequent processing steps such as extrusion and molding (Fu, 2008)

Despite size variations, patterns, and composition disparities, making noodles is uniform for all varieties. On the contrary, Hormdok and Noomhorm (2007) produced noodles using a distinct approach. Rather than dough, rice flour is homogenized with water in the ratio of 2:5 to form a slurry. After an hour, the slurry was transferred into an I mm thick stainless vessel to mold a sheet. Steaming was done for 240 seconds and cooling at room temperature. The sheets are then sliced into strips of 3mm thickness and moisture content reduced to 10% at 40 °C. These two methods generally prepare rice noodles.

Rice vermicelli (*bihun*) is produced from high amylose flour, obtained by rice grains' wet milling. After sifting and pulverizing the flour, it is kneaded into balls. The dough is then pre-cooked for 20 minutes in boiling water or steamed to spur surface gelatinization. Kneading is repeated to ensure that the gelatinized starch is evenly homogenized throughout the dough. The dough is extruded to make noodle strands cooked in boiling water. Soon afterwards, the cooked noodles are cooled in cold water, strained, and dried by placing them in racks (Fu, 2008; Nura *et al.*, 2011)

### 2.3.2 Flat Rice Noodles (*Kuay Teow)*

Flat rice noodles are well known in Japan, Thailand, Malaysia, and Southern China. The procedure engaged with making rice noodles in Japan entails; washing processed Rice, after which they are beaten, steamed, kneaded, and made into sheets. The dough is set in a turning warmed vessel to shape sheets. The sheets are subsequently positioned in a liner, inducing incomplete starch gelatinization. The noodle is kept 1-2 mm thick before slitting (Hormdok & Noomhorm, 2007; Thomas *et al.*, 2014).

### 2.3.3 Dried Rice Noodles

Dried (dehydrated) noodles are prepared by drying fresh rice noodles (Figure 2.2). Limiting the noodle's biochemical reactions and microbial activities can extend its shelf life. This can be realized by reducing the amount of water in the noodle strands through the drying process. Air drying, vacuum drying, or deep frying are techniques employed to reduce noodles' moisture content (Fu, 2008). The adoption of vacuum drying is a novel drying technique for noodles. Vacuum-drying of frozen noodles is customarily done to produce noodles of better quality in terms of texture and cooking characteristics (Piwińska *et al.*, 2016). Water evaporation happens under lowered pressure during vacuum drying (Jaya & Das, 2003). As a result of the increasing gradient of pressure between the inner and outer regions of the dried product, decreased pressure improves mass transfer from the core of the noodle to the surface (Alibas, 2007). Furthermore, the vacuum lowers the boiling point of water, resulting in a lower drying temperature requirement (González *et al.*, 2021).

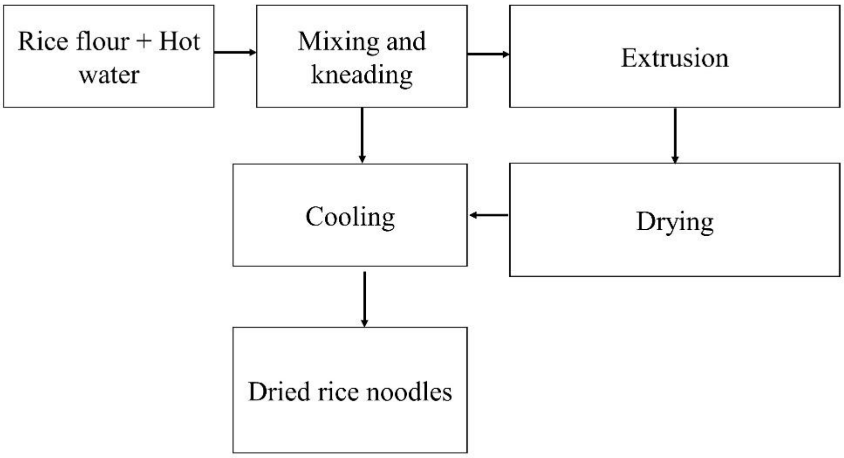


Figure 2.2 Preparation of dried rice noodles

Air drying could be done by using hot and cold air at (>70°C) and (<50°C), respectively. The temperature and relative humidity are harmonized in the drying chamber, the raw strands' location. During air drying, water vaporizes from the noodles' surfaces. The gradient of the air vapour's partial pressure and the noodle surface's vapour pressure provides the dynamic force needed to remove water from the noodles. The airflow rate, temperature properties of the noodles, and relative humidity are the critical factors that regulate how noodles can be dried. The presence of salt influences water diffusion in the course of drying. Inadequate dehydration causes fracturing and damage to noodles' strands, affecting textural handling and cooking properties (Fu, 2008; Thomas *et al.*, 2014). Noodles shrink when the noodles start to lose moisture. The noodle's surface experiences tension, while compression occurs in the inner parts and finally leads to strands' damage.

In the dried noodle-making process, the drying conditions are crucial. They influence the final product's appearance (colour, surface texture, and specks) as well as its cooking behaviour.(Mercier *et al.*, 2011)

Furthermore, water evaporates largely from the product surface during air drying, which may result in the production of a surface barrier. As a result, natural moisture transmission is hampered, and internal tensions in the product may develop, resulting in cracks and fractures in the noodles (Piwińska *et al.*, 2016)

### 2.3.4 Instant Rice Noodles

To prepare instant rice noodles, rice grains with high amylose content are partially gelatinized by steaming the rice flour. The rice flour produced from the process has increased water-binding capacity, which is crucial in reducing dough stickiness and forming firmer noodles and has a good mouthfeel. Like the preparation of fresh rice noodles, the rice flour and some portion of potato and tapioca starches are mixed with hot water and via the kneading process to produce a uniform dough that is eventually extruded. The extruded noodles are then steamed to complete the starch gelatinization and rinse the sticky starch granules on the noodles' surface. The steamed rice noodles are eventually dehydrated to produce instant rice noodles, which can be cooked quickly or heated in a microwave with water (Tong, 2020).

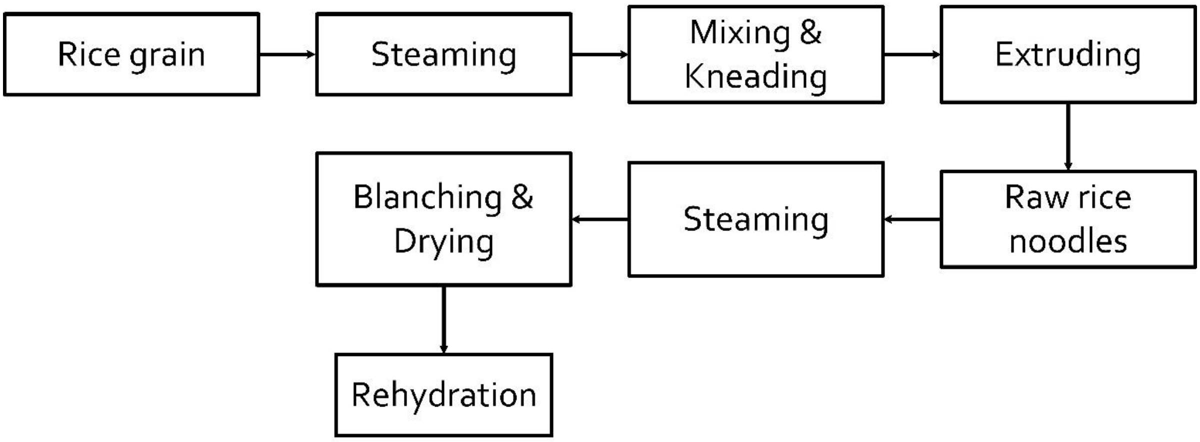


Figure 2.3 Preparation of instant rice noodles (Toh, 1998)

## 2.4 Quality of Rice noodles

Rice noodles are assessed based on their cooking, textural, nutritional, and organoleptic properties. Consumers prefer rice noodles with fine unbroken strands, white, and uniform sizes and shapes. Rice noodles that cook for a short time with minimal cooking loss are highly preferred. The texture of noodles is an essential factor that determines consumer acceptance. Rice noodles are considered to have a good texture if they are relatively hard and have high cohesiveness and chewiness (Kasunmala *et al.*, 2020). Rice noodles with relatively high springiness and chewiness exhibit better organoleptic appeal to consumers (Yi *et al.*, 2017).

### 2.4.1 The texture of rice noodles

The texture of rice noodles is simply the surface mouthfeel and the resistance to chewing of the noodles. The consumer acceptability of rice noodles is dependent on the textural properties of rice noodles (Lubowa *et al.*, 2021). The texture of rice noodles can be evaluated using trained or semi-trained panelists to perform a sensory evaluation. However, this process is time-consuming, especially for an enormous sample size. Therefore, the Texture Profile Analyzer (TPA) proposed by Szczesniak and Bourne (Szczesniak, 2002) can be used to measure the textural properties of solid food materials, including rice noodles (Wee *et al.*, 2018). It is the most straightforward and frequent technique to relate instrumental measurement with sensory evaluation. The TPA method is a 2-time compression type test from which parameters such as hardness, chewiness adhesiveness, cohesiveness, fracturability, springiness, gumminess, chewiness of the noodles can be obtained (Nishinari *et al.*, 2019).

Hardness is the force required to cause a pre-determined deformation. It also measures the resistance of noodles to compressions which is the maximum force of the first compression (Wee *et al.*, 2018). Chewiness reflects the energy required to break down the noodles while chewing before swallowing. Cohesiveness reflects how well the noodles withstand the second deformation, affecting the noodles' chewiness, showing the extent of breakdown of the noodles' structure during chewiness (Wangtueai *et al.*, 2020). The noodles' ability to return to their original shape after compression is called the noodle's springiness. While the degree of adherence of the noodle on the probe after the first compression is the adhesiveness of the noodle (Szczesniak, 2002).

The textural properties of rice noodles are influenced by various factors such as the properties of rice flour, such as the amylose/amylopectin ratio of rice starch, the protein, and lipid composition, the processing conditions (Loubes *et al.*, 2016).

### 2.4.2 Cooking quality of rice noodles

The cooking quality of noodles can be evaluated by measuring the length of cooking time, the cooking loss, and the cooking yield. The cooking quality of noodles is critical to noodles' sensory and textural properties (Karim & Sultan, 2014). Starch gelatinization, protein coagulation, and other structural changes occur in proteins during cooking. These account for how long it takes to get the noodles properly cooked, their water retention capacity, and their ability to withstand the cooking processes and maintain their structure.

Consumers prefer noodles with a short cooking time, less cooking loss, and high cooking yield (Ahmed et al., 2016; Karim & Sultan, 2014). Hydrocolloids, protein crosslinking agents, and the physicochemical properties of rice flour affect the cooking quality of rice noodles.

Noodles are usually cooked in boiling water, and the time taken for the white core in the center of a noodle strand to disappear is the optimum cooking time (Hatcher et al., 2009). Rice noodles cook faster than wheat-based noodles. The primary raw material for rice noodles, rice flour, does not contain gluten. Robust protein networks by gluten limit water ingress into the noodles, thus elongating the starch gelatinization, a precursor for the noodles to be cooked (Karim & Sultan, 2014. Tan et al., 2018). The cooking time of rice noodles is influenced by the rice starch properties and other additives such as hydrocolloids and starches. Rice noodles prepared by blending rice flour with other starches have a longer cooking time due to alteration in the starch's gelatinization temperatures, which ultimately expands the water retention capacity of the noodles (Qazi *et al.*, 2014).

The cooking loss of rice noodles shows the number of substances lost from the noodles during cooking. It is indicative of the structural integrity of the noodles. Rice noodles with high cooking loss are undesirable because they become sticky due to increased leaching of amylose and starch recrystallization. According to the Chinese standard for starch-based noodles, noodles with a maximum of 10% cooking loss are acceptable according (Raungrusmee et al., 2020; Tan et al., 2009). Rice flour particle size, as well as the starch properties, affect the cooking loss. Rice noodles produced from rice flour with intermediate particle size (100 - 140µm) have a lower cooking loss when compared with those with larger particle sizes (Kim et al., 2019). Rice noodles prepared from rice flour with high amylose content have less cooking loss. Also, including protein isolates and protein crosslinking imparts structural integrity on the noodles, minimizing the cooking loss (Kim et al., 2014).

Cooking yield can be used to estimate the water retention capacity of the noodles. During cooking, noodles absorb water and increase weight (Ahmed et al., 2016; Lu & Collado, 2019). The differences in the cooking yield of rice noodles with noodles made from wheat and other flours are due to differences in amylose concentrations, swelling power, and the pasting properties of starches from different sources (Qazi *et al.*, 2014).

### 2.4.3 Sensory properties of rice noodles

Although some textural properties are evaluated visually and instrumentally, a significant evaluation is done in the mouth, hence the essence of sensory evaluation to determine noodles' consumer acceptability. The important sensory attributes of noodles include taste, appearance, flavour, mouthfeel, and overall acceptability (Lu & Collado, 2019).

Appearance is a critical factor for product marketability and interferes with flavour perception. Quality rice noodles must have a smooth surface, unbroken and uniform strands, and white without any form of discolourations (Ahmed et al., 2016). The flavour of noodles is another important sensory property as it indicates the smell and taste. Rice-based noodles' aroma is affected by the rice variety and other additives such as starches and hydrocolloids (Fari et al., 2011).

## 2.5 Critical physico-chemical processes that affect the quality of rice noodles

### 2.5.1 Gelatinization

Gelatinization is one of the most crucial processes starches undergo during processing, which causes changes in its properties. It occurs when starch is heated in the presence of water, leading to the swelling of starch granules, leaching of amylose, and forming a paste (Li et al., 2020).

Rice flours with small starch granule size and higher amylose have low gelatinization temperatures. However, moisture content, additives, and cooking time also affect rice starch's gelatinization temperature (Guo et al., 2018).

The quality of rice noodles is affected by the method of gelatinization. Preferably, some rice flour is pregelatinized and then mixed with the remaining rice flour before complete gelatinization (Yalcin & Basman, 2008). However, a complex process, rice noodles produced using this two-gelatinization process reduced hardness and better flavour.

### 2.5.2 Retrogradation

Retrogradation is the process where gelatinized rice, when left to stand for some time, re-agglomerates and changes from the more crystalline α- starch structure to the insoluble β-structure state (Liu et al., 2020). In rice noodles, retrogradation can be long-term or short-term. Short-term retrogradation increases the noodles' toughness by recrystallizing the gelatinized starch when left to stand for a while in either cold water or a particular temperature (Lu & Collado, 2019). Unlike short-term retrogradation, fresh rice noodles break easily and become tough when left to stand for a very long while after production, which is the onset of deterioration that reduces consumer acceptability.

## 2.6 Different technologies employed to enhance the quality of rice noodles.

### 2.6.1 Aging of rice grains

After harvesting rice paddy, they are stored in an environment with monitored temperature and relative humidity for a given duration. The aim is essential to obtain high-quality rice grains. During aging, the stored rice experiences diverse changes in the physico-chemical, which affects its cooking and processing properties (Zhou et al., 2002). In waxy Rice, aging increased the short chain of amylopectin and starch viscosity (Huang & Lai, 2014). On the other hand, Zhou *et al.* (2016) discovered disulphide linkages produced during the oxidation of proteins and increased strength of starch micelle binding retard the swelling of starch granules, thus improving the texture of cooked noodles. Additionally, free fatty acids, being one of the products formed during the aging process, will form a complex consisting of amylose, carbonyl compounds, and peroxides and further formation of carbonyl compounds, which favourably influence the pasting and textural properties of the cooked rice noodle.

Generally, high amylose rice grains (Indica rice) are preferred for rice noodles (Xuan *et al.*, 2020). Some researchers have suggested that noodles with desirable characteristics can only be obtained from aged rice grains (Hormdok & Noomhorm, 2007; Zhou et al., 2003; Zhou et al., 2016). Rice noodles prepared using aged, polished rice flour had better characteristics than those made from freshly harvested rice grains (Yi *et al.*, 2019b). According to Zhi-min *et al.* (2010), rice paddy aged 0-1.5 years at 37°C can elevate the tensile strength and elongation of non-fermented rice noodles. Park *et al.* (2012) posited that the alterations critically influence rice cooking and eating quality in pasting properties. Also, changes in the rice grains' starch component during aging have been considered critical in the overall quality of rice noodles and other rice-based noodles (Wu *et al.*, 2019). Yi *et al.* (2020) affirmed that the aging duration, variety, and fine starch structure affect rice noodles' quality. Rice noodles prepared with aged rice paddy had better textural characteristics than those produced with freshly harvested rice grains. While we appreciate these researchers' efforts, the longtime taken to aged rice paddies is a significant concern, even as rice noodles' consumer acceptability made with aged rice paddy is yet to be verified.

### 2.6.2 Fermentation of rice grains

Fermentation alters rice grains' thermal properties by increasing the gelatinization enthalpy while reducing the gelatinization temperature (Lu et al., 2003). During fermentation, the various biochemical processes, such as enzymes and other metabolic materials, affect rice noodles' quality. For example, while amylase activity, lipase reduces rice grains' sugar content, whie trypsin decreases the ash, protein, and fat content of rice (Lu *et al.*, 2005). During fermentation, the starch particle size increases while the starch viscosity decreases. Also, lactic acid production reduces the fermenting broth's pH with increasing amino acids, γ-aminobutyric acids (GABA), and total solids, without a corresponding increase in starch and amylose concentrations (Kradangar & Songsermpong, 2015).

Rice noodles produced from fermented rice grains were reported whiter, chewier, and better appearance, with increased starch content due to decreased protein and fat content compared to those prepared using unfermented rice grains (Lu et al., 2005). Even though the fermentation process had a significant effect on the aroma, the demerit of this process is the extensive long period required and the production of lower molecular weight sugars such as glucose and maltose, which had adverse effects on the organoleptic properties of the noodles (Lu *et al.*, 2008; Yi *et al.*, 2019a)

Due to the adverse effects of some environmental microbes on the rice noodles produced from fermented rice grains, some selective inoculation of yeast and lactic acid-forming bacteria have been employed to improve and fasten the rate of fermentation, which ultimately produced rice noodles of better quality, though with reduced protein content with increasing starch concentrations (Cho *et al.*, 2019; Yi *et al.*, 2019a)

The Chinese and some South Asians usually ferment rice grains before milling when preparing rice noodles (Lu *et al.*, 2009). Starch granules from fermented rice flour have low gelatinization temperature, higher swelling power, and resistance towards breakdown (Yang & Tao, 2008). A fine structure was formed from the resulting gel with a gradual retrogradation rate, which produces rice noodles with the desired textural quality. Noodles made from fermented rice grains have better organoleptic properties than unfermented ones (Lu *et al.*, 2003). Reduced ash, protein, and lipids were observed, and deformation of the crystalline starch granules and their chemical composition. These changes facilitated hydrogen bondings amid starch molecules in rice flour and the finished product. A decrease in the rice starch's breakdown and setback velocities were observed during fermentation, created by the slight damage and collapse of the crystalline starch molecules. This is undoubtedly responsible for the observed retrogradation rate on fermented rice noodles (Yang & Tao, 2008).

### 2.6.3 Use of hydrocolloids and other additives.

Alginate is a functional dietary fibre that has found usefulness in rice flour noodles. Commercially, they occur as Sodium salts and act as a thickening and gelling agent. However, $Ca^{2+}$ is employed to obtain irreversible gelation of alginate (Lubowa *et al.*, 2021). According to Koh *et al.* (2009), alginate's surface setting with calcium helps improve rice noodles' texture. In their findings, small amounts of alginate (0.1-02%) were able to bind the starches, reducing cooking loss in noodles, which showed alginate could form a smooth network, suspending starch networks, thereby improving the textural characteristics of the rice noodles. Nitta *et al.* (2018) showed that the Japonica rice noodles' firmness could be strengthened by the $Ca^{2+}$-induced setting of a small quantity of alginate and low methoxyl pectin. In their report, the noodles' textural characteristics could be influenced by the alginate, low concentrations of methoxyl pectin, and calcium chloride immersion time. A little alginate was enough to produce Japonica noodles with improved firmness and less sticky, though the final product's functionality and the glycemic index were not determined. The inclusion of alginate and Calcium chloride in rice flour noodles substituted with 10% okara enhanced the noodles' cooking and textural properties (Kang *et al.*, 2018). Noodles containing okara exhibited reduced water-absorption capacity and swelling index, and these characteristics made the noodles have a coarse and hard texture. Noodles with a higher concentration of okara were harder and more adhesive, and less cohesive. Wandee *et al.* (2015) utilized canna starch and its by-products to improve rice noodles' quality, were crosslinked canna starch increases rice noodles' tensile strength and extensibility. The high gelatinization of rice and canna starch resulted in a homogenous dispersion of disrupted starch granules, producing noodles with high tensile strength. The results also showed that 20% debranched canna starch could improve the noodles' nutritional qualities. When debranched and retrograded starch was added at amounts greater than 20%, the noodles prepared had undesirable textural and cooking characteristics.

According to Wang *et al.* (2018), rice noodles with acceptable textural characteristics can be made by substituting rice flour with 40% of annealed rice starch. The noodles were of better quality than those prepared with pure native rice starch noodles.

The application of different hydrocolloids and their influence on texture and other rice noodles characteristics are well documented (Kasunmala *et al.*, 2020; Koh *et* *al.*, 2009; Loubes *et al.*, 2016; Raungrusmee *et al.*, 2020; Srikaeo *et al.*, 2018). Hydrocolloids like xanthan gum (XG), Guar gum, hydroxypropyl methylcellulose (HPMC) assist in the formation and stabilization of the gluten-free network by controlling the water retention capacity and enhancing the intermolecular dough viscosity (Loubes *et al.*, 2016; Padalino *et al.*, 2016; Pan *et al.*, 2016). The texture and cooking properties of rice noodles were improved by adding Xanthan gum (Kasunmala *et al.*, 2020). However, an increase in gum amount significantly influenced the texture and cooking properties of the rice noodles. According to Raungrusmee *et al.* (2020), an increase in the concentration of xanthan gum in the production of gluten-free rice-based noodles led to the improved tensile strength of the resultant noodles.

Further incorporation of inulin reduced the glycemic index and elevated the cooking time and firmness of the noodles. Srikaeo *et al.* (2018) explored the effects of guar gum, carboxymethyl cellulose, and xanthan gum on dried fermented rice noodles' physical properties. Xanthan gum and guar gum enhanced the textural and cooking properties of the noodles. However, the inclusion of carboxymethyl cellulose yielded noodles with the best physical properties.

### 2.6.4 Hydrothermal treatment of rice flours and starches

Hydrothermal treatments increase starch crystallinity, amylose -amylopectin alignments, and starch granules (Jacobasch *et al.*, 2006). Annealing (treating starch with surplus water (> 65% w/w) and heat-moisture treatment (HMT) (which is utilized for low moisture starch (<35%) are two commonly used hydrothermal treatments employed to transform the properties of starch. Rice noodles made by substituting some rice flours with hydrothermally treated (110°C, 1.5 h) or annealed (55°C, 24 h) rice starches were found to possess better textural and cooking qualities than the commercial rice noodles

(Hormdok & Noomhorm, 2007). The rice noodles made from composite flours had less paste viscosity because of restricted starch swelling. The use of response surface methodology (RSM) to determine the optimum conditions for annealing rice flour suitable for making fresh rice noodles was investigated by Cham and Suwannaporn (2010). Rice noodles made from flours hydrothermally treated had lower adhesiveness due to reducing leaching of amylose due to the formation of crystalline starch arranged in a more orderly manner (Cham & Suwannaporn, 2010). Furthermore, Wang *et al.* (2018) demonstrated that annealing treatment could improve rice starch's physicochemical properties, which successively enhances the finished product's qualities. Rice noodles made from annealed rice starch showed a lower cooking loss, with increased firmness and smoothness than those made from commercial starch. This could be attributed to improved starch retrogradation, which enhances gel formation. The influence of heat-moisture treatment of starch on the textural properties of cooked rice noodles was investigated by Choi and Koh (2017). Results showed that rice noodles' textural and cooking properties were improved by starch annealing for 3h at room temperature to remove water-soluble molecules.

## 2.7 Soy protein isolate (SPI) and its functional properties.

Soybeans have been an excellent source of proteins in Asia and are consumed in various forms such as soymilk, soy curd (*Tofu*), fermented soy paste (miso), and others. Soy protein isolate (SPI) is a plant-derived protein source that is easily digestible and absorbable and has an excellent essential amino acid composition (Singh *et al.*, 2008). SPI is a nearly 90 % pure protein and has been extensively used in several food applications because of its excellent nutritional characteristics, ease of processing, and relatively inexpensive (Niu, Li, *et al.*, 2017; Thrane *et al.*, 2017). Soy protein has been