Physicochemical Properties of Rice noodles as Affected by Addition of
Canadian Lentil and Chickpea Flours

by

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A Thesis
Presented to
The University of Guelph

The Partial Fulfilment of requirements
for the degree of
Master of Science
In
Food Science

Guelph, Ontario Canada
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ABSTRACT

Physicochemical Properties of Rice noodles as Affected by Addition of Canadian Lentil and Chickpea Flours

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University of Guelph, 2017

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This thesis is an investigation of the effect of incorporating 15, 30 and 50% Canadian lentil (LF) and chickpea flour (CF) into rice flour (RF) on the physiochemical and sensory properties in novel rice noodles. The pulse fortified rice noodles exhibited increased dietary fiber (DF) content ranged from 5.70 to 11.29 g/100 g dry mass (DM) as compared with rice noodle of 2.31 g/100 g DM of DF. The protein content of novel rice noodles was improved from 7.4 to 13.4 g/100 g DM with increased concentration of pulse flour. The novel rice noodle protein had a balanced essential amino acid profile with significant enrichment of lysine, arginine, leucine, and phenylalanine in comparison to that of rice noodle. Furthermore, the novel rice noodles had increased antioxidant activities, due to the improvements of total phenolic and flavonoid components. The 50% CF substitution and 30% LF substitution had a predicted Glycemic Index (pGI) of 59 and 63, respectively, which was significantly lower than that of rice noodle (pGI = 67). Sensory evaluation tests revealed that CF fortified rice noodles exhibited higher sensory scores compared with that of LF fortified rice noodle. E.g. 50% CF fortified rice noodles had a similar overall sensory score that of rice noodles. In conclusion, the 50% CF fortified rice noodle had beneficial nutritional profiles and displayed a greater possibility to be accepted by the consumers.
Acknowledgements

The financial support from Saskatchewan pulse growers (PSS1433), the technical support from Guelph Research and Development Center (GRDC), Agriculture and Agri-Food Canada (AAFC), especially Cathy Wang from the lab of Dr. Steve Cui, and food science department at the University of Guelph, is gratefully acknowledged. Furthermore, the technical support and some guidance and advisory from Dr. Shaoping, Nie and Dr. Mingyong, Xie at Nanchang University, Nanchang, China is gratefully appreciated. I would also like to thank all the participants from the Nanchang University for their participation in the sensory survey who supported the work in this way and helped me getting quality results. Lastly, all the guidance, advisory, encouragement and patience from Dr. Steve W. Cui, Dr. H. Douglas Goff and Dr. Lisa Duizer from the University of Guelph is sincerely appreciated.
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<th>Definition</th>
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<tbody>
<tr>
<td>$\Delta H$</td>
<td>gelatinization entropy</td>
</tr>
<tr>
<td>Ala</td>
<td>Alanine</td>
</tr>
<tr>
<td>AMG</td>
<td>amyloglucosidase</td>
</tr>
<tr>
<td>Asp</td>
<td>Aspartic acid</td>
</tr>
<tr>
<td>BDV</td>
<td>breakdown viscosity</td>
</tr>
<tr>
<td>C15:R85</td>
<td>novel rice noodle made with 15% Chickpea flour substitution</td>
</tr>
<tr>
<td>C30:R70</td>
<td>novel rice noodle made with 30% Chickpea flour substitution</td>
</tr>
<tr>
<td>C50:R50</td>
<td>novel rice noodle made with 50% Chickpea flour substitution</td>
</tr>
<tr>
<td>C$_\infty$</td>
<td>equilibrium constant</td>
</tr>
<tr>
<td>CF</td>
<td>Chickpea flour</td>
</tr>
<tr>
<td>Con A</td>
<td>concanavalin A</td>
</tr>
<tr>
<td>CVD</td>
<td>cardiovascular diseases</td>
</tr>
<tr>
<td>Cys</td>
<td>Cysteine</td>
</tr>
<tr>
<td>DF</td>
<td>Dietary fiber</td>
</tr>
<tr>
<td>DG</td>
<td>degree of gelatinization after extrusion of the rice noodles</td>
</tr>
<tr>
<td>DM</td>
<td>Dry weight base</td>
</tr>
<tr>
<td>DMSO</td>
<td>dimethyl sulphoxide</td>
</tr>
<tr>
<td>DPPH</td>
<td>2-2-diphenyl-1-picrylhydrazyl</td>
</tr>
<tr>
<td>DPPH</td>
<td>DPPH radical scavenging activities</td>
</tr>
<tr>
<td>DSC</td>
<td>Differential Scanning Colourimetry</td>
</tr>
<tr>
<td>EAA</td>
<td>Essential amino acid</td>
</tr>
<tr>
<td>Fe (II)</td>
<td>Fe (II) equivalent</td>
</tr>
<tr>
<td>FRAP</td>
<td>Ferric reducing antioxidant power</td>
</tr>
<tr>
<td>FV</td>
<td>final viscosity</td>
</tr>
<tr>
<td>GAE</td>
<td>gallic acid</td>
</tr>
<tr>
<td>GI</td>
<td>glycemic index</td>
</tr>
<tr>
<td>Glu</td>
<td>Glutamic acid</td>
</tr>
<tr>
<td>Gly</td>
<td>Glycine</td>
</tr>
<tr>
<td>GOPOD</td>
<td>glucose oxidase, peroxidase and 4-aminoantipyrine</td>
</tr>
<tr>
<td>h</td>
<td>hours</td>
</tr>
<tr>
<td>HI</td>
<td>hydrolysis index</td>
</tr>
<tr>
<td>His</td>
<td>Histidine Arg=Arginine</td>
</tr>
<tr>
<td>IDF</td>
<td>Insoluble dietary fiber Ile =Isoleucine</td>
</tr>
<tr>
<td>K</td>
<td>kinetic constant</td>
</tr>
<tr>
<td>L15:R85</td>
<td>novel rice noodle made with 15% lentil flour substitution</td>
</tr>
<tr>
<td>L30(F): R70</td>
<td>novel rice noodle made with 30% lentil (F) substitutions</td>
</tr>
<tr>
<td>L30(P):R70</td>
<td>novel rice noodle made with 30% Lentil flour that contained 0.25% of psyllium</td>
</tr>
<tr>
<td>L30:R70</td>
<td>novel rice noodle made with 30%</td>
</tr>
</tbody>
</table>
lentil flour substitution

L50:R50 = novel rice noodle made with 50% lentil flour substitution

lentil (F) = The filtrates of lentil flour that did sieving through 80 mesh

lentil (N) = The large particles of lentil flour that did not sieving through 80 mesh

Leu = Leucine

LF = lentil flour

Lys = Lysine

MC = Moisture content

Met = Methionine

min = Minutes

ND = not determined

NRS = Non-resistant starch

OA = over acceptability

ORAC = oxygen radical absorption capacity

\( pGI = \) predicted/estimated glycemic index

\( pGI_a = \) predicted glycemic index calculated by Granfeldt et al. (1992): 8.198 + (0.862*HI)

\( pGI_b = \) predicted glycemic index calculated by Goñi et al.(1997): \( pGI_b = 39.71 + (0.549*HI) \)

Phe = Phenylalanine

PT = pasting temperature

PV = peak viscosity

R1 = late harvested Indica rice

R2 = early harvested Indica rice

R3 = Japonica rice

RDS = rapidly digestible starch

RE = rutin

RF = Rice flour

RN 1 = commercial rice noodle that used as 1st control

RN 2 = rice noodle made in the lab that used as 2nd control

RS = Resistant starch

RVA = Rapid Visco Analyzer

SBV = setback viscosity

SD = Standard deviation

SDF = soluble dietary fiber

SDS = slowly digestible starch

Ser = Serine

TAA = Total amino acid

Tc = Conclusion Temperature

TDF = Total dietary fiber

TE = Trolox

TFC = Total flavonoid content
Thr = Threonine

To = Onset Temperature

Tp = Peak Temperature

TPA = Texture profile analysis

TPC = Total phenolic content

TS = Total starch

TV = through viscosity

Tyr = Tyrosine

Val = Valine

WTP = willingness of purchase

wwb = Wet weight base
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Chapter 1. Introduction and overview

Rice noodles are a very popular food in Asian countries, including China (Hormdok & Noomhorm, 2007). Unfortunately, the traditional rice noodle is high in carbohydrates and low in high-quality protein and dietary fiber (DF) (Mubarak, 2005). Specifically, rice protein is sufficient in cysteine and methionine, but low in lysine (Carvalho et al., 2013). There are studies suggesting that a high intake of rice or rice products based diet (high glycemic load) increases the chance of developing type II diabetes in Chinese and Japanese population (Hu, Pan, Malik, & Sun, 2012; Nanri et al., 2010; Villegas et al., 2007). With the increasing public awareness of the importance of a healthy diet, popularity of rice noodle faces a challenge. Thus, the enrichment of the traditional rice noodle with functional nutrients (such as DF and balanced amino acid profile) has proved to be necessary.

Pulses (beans, peas, lentils & chickpeas) contain high quality protein, DF, starches, vitamins, minerals, and other important nutrients including carotenoids and isoflavones (Boye, Zare, & Pletch, 2010; Chung, Liu, Donner, et al., 2008; Tosh & Yada, 2010; B. Zhang et al., 2015). Pulse starches are high in amylose content (approximately occupied 30% of overall starches), which is the major reason why pulse starch has strong gelling stability. The stronger gel formed during retrogradation of pulse starches make them more resistant to breakdown by digestive enzymes, which leads to a lower Glycemic Index (GI) (Fredriksson et al., 2000). Pulses are rich in total dietary fiber (TDF) content in comparison to rice products, which is another major reason for pulses to be considered as low GI food (GI ≥ 55), which lowers the postprandial glucose response (Sajilata, Singhal, & Kulkarni, 2006; Slavin, 2013). As a result, pulses can benefit people with Type II diabetes, reduce the incidence of cardiovascular diseases, help in weight-loss, and control of obesity (Giuberti, Gallo, Cerioli, Fortunati, & Masoero, 2015; N. Wang, Warkentin, Vandenberg, & Bing, 2014). Although pulses are high in protein content, pulse protein is low in cysteine and methionine but has considerable amounts of lysine, leucine, aspartic acid, glutamic acid, and arginine (Boye et al., 2010). Canada is the largest pulse producer and exporter worldwide. However, the average daily pulse consumption in Canada is limited because of insufficient scientific research and available
technologies for incorporating pulse-based ingredients into staple foods.

Incorporating pulse into rice noodles will lead to many beneficial outcomes. First, the combination of rice and pulse proteins (e.g. pea proteins) offers a superior balanced amino acid profile that is comparable to dairy/egg proteins (Duranti, 2006). Furthermore, incorporation of pulses with high TDF into the rice noodle could reduce its GI, hence, potentially benefit people with Type II diabetes (Marinangeli & Jones, 2012). Moreover, the pulse flour modified rice noodles are advantageous for people with celiac disease, who are sensitive to gluten, as both rice and pulse flour do not contain gluten (Sandhu & Kaur, 2010). Lastly, mixing Canadian pulse ingredients into traditional Chinese foods, such as starch noodles or rice noodles, will increase the market potential of Canadian pulses in China or even in Canada. Thus, novel rice noodles could be a new market for Canadian pulses. Overall, fortification of rice noodles with pulses will enrich the nutritional values in comparison to traditional rice noodle and will expedite the new market potential for Canadian pulses.

The aim of this study was to: (1) Characterize Canadian pulses, such as lentils, chickpea, and pea flours, as well as rice flours for making pulse fortified rice noodles; (2) investigate the effects of adding selected Canadian pulse ingredients on the nutritional characteristics and qualities of rice noodles; (3) develop a novel formulation of the fortified rice noodle products with good texture, flavour, consumer acceptability and with increased nutritional values, which could benefit people with Type II diabetes and celiac diseases.
Chapter 2. Literature review

2.1. Starch

Rice noodles are considered as a staple food, because they contain a high amount of carbohydrate (mostly in the form of starch). Besides, as a major energy source for the human diet, rice starch acts as a key indicator for detecting or modifying the quality of rice noodles. The information below provides the characteristics of starch, perhaps for better assisting in acknowledging the rice noodle processing.

2.1.1 Structure and granular morphology

Starch often is the major component of staple food products (such as rice, bread, pasta and potatoes). Starch is formed as discrete particles in plants, defined as granules. The granules vary in shapes (oval, spherical, round, elliptical, disks, angular, polygonal, etc.) and sizes (0.5 to 175μm), usually dependent on plant sources and their physiochemical properties. Starch granules are composed of two structural distinct α-D-glucan components: amylopectin and amylose. Amylose and amylopectin are primarily associated with the colloidal characteristic of starch. Rice starch granule is mainly composed by amylopectin, which is a substantially branched component as compared with amylose (Hizukuri, 1985). It consists mainly of the α-(1→4) linked D-glucopyranosyl residues, 5 to 6% of which having branch points through (1→6) linkage. Amylose is the minor component of starch granules, composed of α-(1→4) linked D-glucopyranosyl residues with a slight degree of branching and often consider as a straight chain in comparison with amylopectin (Hizukuri, Takeda, Yasuda, & Suzuki, 1981).

The starch granules are usually formed by alternating semi-crystalline areas and amorphous regions that result in a ringed pattern similar to tree growth rings (Rindlava, Hulleman, & Gatenholma, 1997; Wani et al., 2012). Within the growth ring, both semicrystalline and amorphous regions are further divided into large, with 20 to 500 nm in diameter, and small, with approximately 25 nm in diameter spherical blocklets. However, the blocklet that exists in the semicrystalline growth ring composed by several replications of alternating amorphous and crystalline lamellae (Wani et al., 2012). The amylose might be located primarily in the amorphous growth rings with some less ordered amylopectin and less crystalline...
regions within the starch granule (Jobling, 2004; W. Morrison, 1995). Precisely, amylose and branch points of the amylopectin compose the amorphous lamellae. Amylopectin is the only constituent in the semicrystalline lamellae. The plant source defines the unique granule size, shape, chemical composition, and structure morphology. Hence, it is possible to identify starches based on their morphological properties when investigating using a light or scanning electron microscope. In addition, the packing of amylose and amylopectin among the starch granules can be revealed by studying their crystalline structure using X-ray diffraction technology. Starch granules exhibit three different types of X-ray diffraction patterns: A, B and C type. Type “A” is usually obtained from cereal starches, while high-amylose and retrograded starches possess type “B” X-ray diffraction patterns (N. Singh, 2011). Type “C” has a combination of A- and B-type polymeric forms and is usually found in the legumes.

2.1.2 Thermal properties of starch (gelatinization and retrogradation)

The investigation of thermophysical properties provides a means of predicting the final quality of starch related food products. During heating within an extreme aqueous environment, starch granules experienced an irreversible order-disorder phase transition known as gelatinization (C. Biliaderis, 2009). Gelatinization is an endothermic reaction (C. Biliaderis, 2009). During this process, the double helical and the crystalline region of the starch granules are disrupted. Gelatinization can be divided into two steps. First, in the present of heat and water cause the granules to swell irreversibly because the hydrogen bonds between amylose and/or amylopectin molecules would break because water takes the place of the polymer, followed by the crystallites separating apart. Secondly, water works as a plasticizer, which results in hydration of starch, and leads to further granular swelling in the amorphous regions, crystalline melting and starch solubilization (C. Biliaderis, 2009). During this process, the amylose leaches out of the granules and viscosity increases. Differential scanning calorimetry (DSC) has been the most common physical method applied in investigating starch gelatinization and retrogradation. The thermal properties measured by DSC can be characterized by gelatinization transition temperatures (T_o, onset temperature, T_p, peak temperature, and T_c, conclusion temperature) and gelatinization enthalpy (∆H) of starch. T_p and ∆H represent the
crystalline quality and the overall crystallinity of the starch, while the $T_0$ and $T_c$ measure the boundaries of the different phases during the transition. $\Delta H$ is calculated based on the area under the endothermic peak produced due to the melting of amylopectin crystallites, which is associated with the disruption of the amylopectin double helices (molecular order) (Cooke & Gidley, 1992).

There are many factors influencing starch gelatinization. The swelling power (water holding capacity of the starches) of the granules is controlled by the amylopectin and has been known to be restricted by the amylose and lipid content within the starch. Amylose, with its inclusion behavior, can bind with free lipids or protein within the starch. This amylose-lipid complex could negatively affect the final gelatinization quality, since they are insoluble in water which prevents them from leaching out (Wani et al., 2012). Thus, this amylose-lipid complex requires higher temperatures to dissociate (N. Singh, 2011). Protein could inhibit water absorption and reduce starch swelling power during gelatinization, but the presence of amylose-protein complexes will lead to higher water holding capacity and increased starch swelling power. Additionally, the presence of a high amount of long chain amylopectin postponed gelatinization and increased swelling power, since more energy or higher temperature are required to dissociate long chains than short chains (Vandeputte, Vermeylen, Geeroms, & Delcour, 2003). Furthermore, a high degree of crystallinity (meaning higher presence of long chain amylopectin) led to stable structures and allowed granules to be more resistant to gelatinization, which resulted in high transition temperatures (Barichello, Yada, Coffin, & Stanley, 1990). Additionally, evidence also suggested that the size of granules account for the difference in gelatinization of different starch materials. The smaller particle size of starch granules allows rapid hydration with greater surface area exposed. Thus, starch granules swell faster and less energy is needed to trigger gelatinization in comparison with bigger sized starch granules (Ahmed, Qazi, Li, & Ullah, 2016). Therefore, the difference in chain length distribution of amylopectin, amylose/amylopectin ratio, granule morphology, amylose-lipids and amylose-proteins complexes, and granule size could all influence the gelatinization of starch.
Furthermore, from the amylose leaching during gelatinization, the viscous solution recrystallizes and forms a gel upon cooling, during which the starch amylose and amylopectin chains realign themselves. This phenomenon has been referred as retrogradation (C. Biliaderis, 2009). During retrogradation, it is usually the linear amylose and linear sections (i.e. shorter chain length) of amylopectin within the suspension retrograde and rearrange themselves to a more ordered phase (crystalline structure) (C. G. Biliaderis & Tonogai, 1991). Hence, retrogradation highly relies on the amylose content and chain length distribution of amylopectin.

On the other hand, higher amount of amylose with lower amount of long chain amylopectin within the starch can easily rearrange themselves upon cooling, result in increasing hardness and elasticity, as well as decreasing stickiness of the final starch containing product. Furthermore, retrogradation of amylopectin takes longer time to reach equilibrium than amylose (Philpot, Martin, Butardo, Willoughby, & Fitzgerald, 2006). The presence of free and uncomplexed lipids could affect the degree of starch retrogradation, as leached amylose could bind with lipids to form amylose-lipid complex during cooling. The amylose-protein complex does not significantly influence the gelatinization process of starch, but the retrogradation. The facilitation of protein-starch interaction delayed the retrogradation process, because it is difficult for the amylose to realign within excessive water environment (Y. Wu, Chen, Li, & Wang, 2010). Therefore, after higher temperature process, the ratio and morphology of amylose and amylopectin are the important indicators for the behavior and functionality of starch containing food materials (Wani et al., 2012).

**2.1.3. Pasting properties**

After amylose leaches out into solution during gelatinization, the starch granules collapse to generate a viscous material called paste (BeMiller, 2007). The pasting properties are commonly measured by a rapid visco analyzer (RVA), which are usually influenced by size, amylose, lipid content and amylopectin structure of starch granule (Ao & Jane, 2007). It is important to investigate the paste properties, to understand how particular starch contained in food will behave during processing and suitability of
particular starch as a functional ingredient in food products. The pasting properties are measured by RVA, including peak viscosity (PV), through viscosity (TV), final viscosity (FV), breakdown (BDV), setback (SBV) and pasting temperature (PT). During the RVA measurement, the starches go through a hot-hold-cool cycle and the pasting curve is presented in Figure 1. With the presence of aqueous environment, the granules absorb water and start to swell when temperature is greater than 50 °C, which allows amylose leaching out and the increase of viscosity. The temperature when viscosity starts to rise is referred as pasting temperature (PT). PT indicates the minimum temperature required to cook the sample. Smaller sized starch granules could contribute to reducing PT because they swell faster and lead to gelatinization early at lower temperature in comparison with bigger sized starch granules (Ahmed et al., 2016). Peak viscosity (PV) is defined as the viscosity at the maximum temperature reached during heating, which is the measure of extent of when the granules collapsed. This factor is highly associated with the water-binding capacity of starch granules, which is defined as swelling power. Also, this parameter usually correlates with the final quality and texture of cooked sample (Gani, Wani, Masoodi, & Salim, 2013; Klein et al., 2013; N. Wang et al., 2014). Through Viscosity (TV) is the viscosity measured at peak temperature. Breakdown viscosity (BDV) indicates the paste stability during cooking of starch by measuring the ease of swollen granules to be disrupted (Joshi et al., 2013). High amylose and fine structure amylopectin suggest the more intact starch structure, which results in higher hot paste stability and low BDV (F. Wu, Meng, Yang, Tao, & Xu, 2015; Yuan, Lu, Cheng, & Li, 2008). As the starch paste cools, the molecules (amylose) start to retrograde. The tendency of the starch paste to reassociate into an ordered structure is defined as the setback viscosity (SBV), which is a key indicator of the final product texture. Amylose content negatively correlates with SBV. High amylose content indicates existence of more linear structure, which the molecules are easier to be re-associated each other, hence, start retrogradation earlier. (F. Wu et al., 2015). Final viscosity (FV) reflects the capability of the sample to develop a viscous paste after the cooling period (N. Wang et al., 2014).
2.1.4 Starch classifications and their characteristics

Many type of starches can be categorized based on their ability to be digested by the human body. Based on the tendency of glucose release and water adaptability of starches in the gastrointestinal tract, starches usually are classified into two categories: digestible starch (DS)/non-resistant starch (NRS) and resistant starch (RS). The DS is further classified into rapidly digestible starch (RDS) and slowly digestible starch (SDS) (N. Singh, 2011). RDS is defined as the part of starch that leads to a quick elevation in the blood glucose concentration after consumption, while SDS refers to the fraction of starch that is digested slower than RDS, but gets digested completely within the small intestine. There are many benefits associated with consuming SDS, such as reducing postprandial glucose levels, increasing lipid response, diluting glycosylated haemoglobin and fructosamine, together with improving insulin sensitivity (Lehmann & Robin, 2007). The resistant starch is the portion of starch that passes through the small intestine without being digested by enzymes and gets fermented by the colonic microflora within the large bowel. Resistant starch behaves as dietary fiber and is considered as a third type of dietary fiber (Bravo, Sidduraju, & Saura-Calixto, 1998; Queiroz-Monici, Costa, da Silva, Reis, & de Oliveira, 2005). The products from the fermentation of resistant starch include methanol, hydrogen, and short chain fatty acids.
acids, which reduce pH level of the large intestine and stimulate the production of beneficial bacteria and
destroys pathogenic microorganisms (Leszczyński, 2004). Many researchers have been investigating how
to incorporate the high resistant starch ingredients into food products with increased physical, nutritional
functionalities and processing stability (Thompson, 2000).

Resistant starch is further classified into four types: RS1 is starch that is inaccessible for digestion
and is usually present in partly milled grains, seeds and legumes or tightly packed structures such as pasta
(Bravo et al., 1998). RS2 is native starch that is resistant to enzyme digestion, found in uncooked foods
such as potato and green banana (Bravo et al., 1998; Raigond, Ezekiel, & Raigond, 2015). RS3 is
retrograded starch or completely hydrated indigestible starch after the material containing starch is heated
in a water accessible environment and then cooled, where the leached amylose reassociates to form
double helices. The significance of RS3 is its excellent thermal stability and it is usually present in
cooked, cooled potatoes, and canned legumes, thus it has been applied in many conventional foods (Bravo
et al., 1998; Haralampu, 2000). RS4 is human-made modified starch formed via cross-linking with
chemical reagent (Sajilata et al., 2006). A diet containing high resistant starch results in several
physiological effects that are beneficial for human health including decreasing rate of glucose released
into the bloodstream, causing the reduction in glycemic and insulinemic postprandial responses after a
meal, decreasing the risk of colorectal cancer and initiating hypocholesterolemia effects (Bravo et al.,
1998). Usually, adults should consume 5 to 6 g/d resistant starch in order to trigger beneficial influences
on insulin response (Behall, Scholfield, Hallfrisch, & Liljeberg-Elmståhl, 2006). Resistant starch (mostly
RS2) could improve digestive health and possibly prevent colorectal cancer by increasing laxation,
beneficial gut bacteria, butyrate and reducing gut pH (biomarker for risk reduction of colon cancer), as
well as healing intestinal ulcerations and defending colonic DNA damage (Warshaw, 2007).

2.1.5 In vitro starch digestibility and glycemic attributes

The glycemic index (GI) is a measure of various high carbohydrate foods corresponding to their
post-meal glycaemia (D. Jenkins et al., 1981). GI is categorized at three levels: low (≤55), medium (55-
69) and high (≥70) GI. With in vitro digestion, the predicted glycemic index (pGI) is usually expressed as a percentage of a reference food, with similar or equivalent carbohydrate level, such as white bread (Goñi, Garcia-Alonso, & Saura-Calixto, 1997). However, instead of actual GI value obtained from in vivo starch digestion, pGI is a calculated value and is not as accurate as GI. GI and resistant starch content are the two most important factors influencing starch digestibility. The method investigated by Englyst, Kingman, and Cummings (1992) is the common method to study in vitro starch digestibility. RDS is referred as the starch that is processed after 20 min, SDS is identified as the starch that is digested during the 20 to 120 min period, while resistant starch is described as the starch that remains undigested after 120 min.

Many factors influence enzymatic starch digestibility including texture, morphological, and rheological properties of food products. Starch hydrolysis is influenced by their crystalline structures (Lehmann & Robin, 2007). However, non-starchy substances such as protein or lipids could act as barriers during the enzymatic hydrolysis by blocking the adsorption sites, which limits the binding of digestive enzymes (Oates, 1997). For example, research had suggested protein fractions, e.g. albumins, globulins and glutenins restrict the binding of amylases (enzyme used for digestion of starch to maltose) by attaching to the protein bodies to form a matrix around starch granules (Hamaker & Bugusu, 2003).

Both high amylose and high resistant starch content can cause pulse starches to have low GI, which is beneficial for moderate insulin response and to regulate glucose metabolism (A. L. Jenkins, 2007; N. Singh, 2011). Furthermore, evidence has suggested that higher amylose content also reduced the GI values, even with high carbohydrate content (Denardin, Walter, da Silva, Souto, & Fagundes, 2007). For example, Mung bean noodles contained high amylose content and higher carbohydrate content, but exhibited low GI values of 28 (Lin, Wu, Lu, & Lin, 2010). The low GI value of mung bean noodle might be due to amylose complexes with lipids, which are known to be resistant to enzymatic attack (Holm et al., 1983). However, the GI of food products could vary with different preparation and cooking methods, processing conditions, GI testing methods or even an alternation in the geographical location (Lin, Wu, & Lin, 2010). For example, Ranawana, Henry, Lightowler, and Wang (2009) pointed out that longer
cooking time increased the glycemic response of basmati rice.

2.2 Rice flour and rice noodle (rice vermicelli)

Rice noodles (also called rice vermicelli) with an elastic texture, smooth and slippery surface are a traditional and popular food in Southern China, including Jiangxi, Yunnan, Hunan, and Guangdong provinces. Many kinds of rice noodles are commercially available according to their geographic location, which they have acquired distinct characteristics, such as Jiangxi-mifen, Guangzhou shahe-fen, Guilin-mifen, and Yunan guoqiao-mixian. Thus, there is not a standard method for processing of rice noodles. However, the basic processing principles are somewhat similar, which involve several major steps, starting with selection of rice material, then cleaning, soaking, grinding, heating, molding, cooling and lastly drying. For manufacturing purposes and prolonging shelf life, rice noodles are usually dried and produced in the form of thin stripes with rectangular or circular cross section (Jiang, Zeng, Zhu, & Liu, 2012). Dry rice noodle has a tough and hard texture, which makes packaging and transportation easier (Fu, 2008). Before serving, dry rice noodles usually need to be cooked again in boiling water, which allows the rice noodle to absorb moisture and soften in texture. Rice noodles could be served both as a staple food and as a side dish and are usually consumed in the form of noodle soups or stir-fried with vegetable and meats (Fu, 2008; B. Kaur, Ranawana, & Henry, 2016).

2.2.1 The chemical components of rice

2.2.1.1 Rice starches

The major constituent of rice is starch, which usually accounts for more than 80% of total components of rice (Q. Liu, Donner, Yin, Huang, & Fan, 2006). Rice starch granules have a type “A” X-ray diffraction patterns. Rice starch granules have angular and polygonal shapes with a smooth surface and are the smallest in size within cereal grains, ranging from 2 to 7 μm (Wani et al., 2012). The starch affects the physical properties of rice related products, such that different rice with precise amylose-amylopectin ratios are utilized for various rice products. Rice starches can be subdivided as glutinous (waxy) and non-glutinous (nonwaxy) starches. The waxy rice starch is low in amylose content (< 5%),
while the nonwaxy rice starch is the opposite, with the amylose reported in the range of 12 to 33%. The amylose content of rice starches differ from 0 to 2% in waxy rice, 2 to 12% in very low, 12 to 20% in low, 20 to 25% in normal or intermediate and 25 to 33% in high amylose rice grains (Ahmed et al., 2016; Widiastuti Setyaningsih, Saputro, Lovillo, & Barroso, 2015). With the variety of amylose content within different rice starches, the \( T_o \), \( T_p \), \( T_c \) and \( \Delta H \) of rice starches ranged from 65.1 to 69.46 °C, 70.24 to 80.06 °C, 74.84 to 88.30 °C, and 3.14 to 6.55 J/g, respectively (Srikaeo & Sangkhiaw, 2014; F. Wu et al., 2015).

For the pasting properties, waxy rice starch exhibited much lower values of PV, TV, BDV, SBV, and FV than non-waxy rice varieties because of low amylose content (0-2%) in the waxy rice starches (Techawipharat, Suphantharika, & BeMiller, 2008; Wani et al., 2012). The PT, PV, TV, BDV, SBV, and FV for RF used for rice noodle production were 87.65 °C, 3336 cP, 2617 cP, 5834 cP, 3217 cP, and 719 cP, respectively (F. Wu et al., 2015). However, these pasting properties of RF could be varied, which are affected by experimental condition, chemical composition of rice, geological condition and etc.

### 2.2.1.2 Other minor components

Rice grains also contain protein, fiber, lipid and ash. Rice protein usually ranges from 6.7 to 13.8% of total components of rice grains (Xie et al., 2014). Rice protein consists mainly of glutelin (~80%), with some minor components of 5% albumin, 12% globulin, and 3% prolamin of the total constituents of rice protein (Wani et al., 2012). Based on amino acid profile, rice protein has limited amount of lysine, but considerably amount of glutamic and aspartic acids and sulfur containing amino acid (cysteine and methionine). The lipid contents in rice range from 0.19 to 2% for varieties of white rice grains (Rohman, Helmiyati, Hapsari, & Larasati Setyaningrum, 2014). The ash content could almost be negligible and does not vary too much in white rice grains (Han, Cho, & Koh, 2011). The fiber content within rice grains is considerably low, ranging from 2 to 4.6 %. There are many varieties of rice, but brown rice is considered as highly nutritious among other rice varieties because of its high fiber content. Specifically, brown rice usually has higher fiber content (3.5 to 4.6%) than regular white rice (1 to 2.8%). However, white rice with high starch and minimal fiber content is popular for applications into food products, such as rice noodles.
Almost all the major components of milled rice play a role in affecting the consistency of rice noodle production, which include starches, proteins, lipids, monosaccharides and ash, whereas amylose and protein contents are the two important quality indicators that control the physical properties of rice noodles (Y. Li, Liang, Yang, Chen, & Han, 2015; Xie et al., 2014). The amylose content influences the gelatinization properties and retrogradation ability of rice flour (RF), thus rice starch significantly influences the qualities of rice noodles (H. Li et al., 2005). With increased amylose content, rice starch could form a stronger gel with reduced adhesiveness and cooking loss, which is desirable for rice noodle quality. On the other hand, the solubility, swelling power, and aging value of rice starch also has a remarkable influence on cooking loss, breaking rate and taste (Y. Zhang, Yang, Wu, & Li, 2003). With the presence of a high amount of long chain amyllopectin and low amount of amylose content, solubility, swelling power and aging time are increased. These conditions lead to increased cooking loss, breaking rate, stickiness, and decreased hardness, which are not desirable for rice noodle production.

Selecting the variety of rice with moderately high amylose content is also necessary for rice noodle processing. The amylose content correlates with digestibility significantly (Chung, Liu, Lee, & Wei, 2011). For instance, amylose content is negatively correlated with RDS. Long grain with 27% amylose content had RDS content of 39%, whereas glutinous rice starch having only 4% amylose content contains 71% RDS (Chung et al., 2011). Besides, amylose content is positively correlated with pGI value. Calrose and Pelde, with the amylose content of 20%, had pGI values of 83 and 93, respectively, while white rice from Doongara with an amylose content of 18% presented a predicted GI value of 64 (Miller, Pang, & Bramall, 1992). Moreover, the majority of rice noodles are produced with moderately high amylose content rice varieties, which intrinsically lead to lowering the GI (B. Kaur et al., 2016). For example, Taiwan vermicelli exhibited a GI value of 68, while Jiangxi vermicelli exhibited a GI of 56, both of them exhibited lower GI values than most of the white rice products (Gatti et al., 1987; D. Jenkins et al., 1981; Rohman et al., 2014).

2.2.2 Selection of raw rice for the production of rice noodles

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Some evidence has been reported that better quality rice noodles are made from RF with at least 22% amylose content of total rice starch (Ahmed et al., 2016; Han et al., 2011). However, not all the high amylose content rice varieties are suitable for rice noodle production. For example, moderate high amylose content lines japonica cultivar (Goamibyeo) and indica cultivar (Chenmaai) with an amylose content of approximately 24% showed desirable cooking and textural properties, which was consistent with above research statement. Yet, the japonica lines of Milyang261 and Suweon517 with an amylose content of 32% and 26%, respectively, had lower cooking quality and noodle strength, whereas, Milyang261 with the highest amylose content among all the tested raw material exhibited the lowest pasting stability (Han et al., 2011). Thus, the rice noodles exhibited better quality than others when the amylose content was 24 to 26% of the total starch (TS) content (Han et al., 2011). Other evidence also suggested that for the suitable rice for rice noodle production, the amylose content of rice starch should be close to 26% (Sun, Ding, Ding, He, & Yin, 2004). Altogether, research has pointed out the composition of rice starch, such as amylose/amylopectin ratios, and chain length distribution of granule are some important aspects that need to be considered to improve the rice noodle quality (Han et al., 2011). Furthermore, protein content also plays a role in affecting the cooked rice noodle texture. Protein inhibits water absorption ability, results in reducing starch swelling power of RF during gelatinization and facilitates retrogradation, and improves the firmness of the cooked rice noodles. Overall, raw rice material with intermediate high amylose and protein content greater than 7% produces better quality rice noodles (W. Zhao, 2008).

Commonly, rice noodles are produced with long grain and nonwaxy rice variety that has moderately high amylose content (22 to 26%) including Indica and Japonica cultivars. But, the Indica rice variety is the most commonly applied variety for rice noodle production (S. Zhao, Liu, Xiong, & Jiang, 2002). In general, Japonica rice varieties tend to be higher in price than Indica rice because Japonica rice has lower production yield and a longer period of maturation. The Japonica rice (Goamibyeo) had lower break rate,
better extensibility and taste of cooked noodles in comparison with *Indica* rice (*Chennmaai*), due to *Japonica* rice has slightly higher amylose and lower fat content than *Indica* rice (Han et al., 2011). The *Indica* rice varieties are an early crop and produce twice yearly: early (the rice variety maturing before 7th month) and late harvested (planted following the harvest of the early crop, and maturing at the end of the year). *Japonica* rice is considered as late or intermediate crop and only harvested once a year, thus it was costly to apply *Japonica* rice for rice noodle production in comparison with *Indica* rice (Bao, Kong, Xie, & Xu, 2004). The late-harvested *Indica* rice is cheaper in price and stickier in quality in comparison with early-harvested *Indica* rice. Therefore, it was recommended to use early-harvested *Indica* rice for rice noodle production, because of their moderately higher amylose content, which results in better firmness and less sticky quality rice noodle (Y. Li et al., 2015). But considering for economy and quality reasons, a blend of the early and late harvested *Indica* rice (which decreases the cost of production), as well as with *Japonica* rice (which improves the taste) is often recommended for the best outcome of rice noodle production.

2.2.3 Manufacturing of rice noodles

The traditional rice noodle is handmade (N. Wang et al., 2014). Briefly, the process starts by cleaning the raw rice to remove dust and other undesirable materials (Y. Li et al., 2015). Then the rice is soaked overnight or longer, which allows the water to penetrate the rice kernel and causes a gaining of the moisture content (MC) of the rice. The properly soaked rice is then ground and sieved to produce RF. RF is made into “dough”, which is extruded or cut to desired shapes. The rice noodles are heated in boiling water for a short period, which permits complete gelatinization of the rice starches (Y. Li et al., 2015; N. Wang et al., 2014). The last step is cooling the cooked rice noodles to around 24-26 ºC, then air-drying. This final step allows the rice noodles to form a stronger gel and provides a smooth and slippery texture, which are all desirable for rice noodles (Y. Li et al., 2015; N. Wang et al., 2014). Commercially, rice noodles are made by rice noodle machines, which is more time and energy efficient. The ground RF is mixed with water into rice slurries, which are subsequently heated and molded through the machine. The fresh rice noodles are air
dried, then, put into drying machine such as ovens to further dehydrate before packaging. The following section describes the three major steps for manufacturing production of rice noodles: milling, extrusion, and drying.

2.2.3.1 Milling process

Rice is usually ground into flour in the process of dried rice noodle production. The purpose of doing so is to make the starch granules more uniform and smaller (Marshall, 1992; Normand & Marshall, 1989). Different milling processes such as dry grinding, semi-dry grinding and wet grinding might show different effects on the gelatinization degree, physical-chemical properties, particle size distribution and damaged starch content of rice, which might affect the qualities of rice noodles. In general, wet grinding could make the starch particles more uniform and smaller, cause less loss of starch content, and reduce the gelatinization enthalpy value. Dry grinding might cause more damage to rice and generate more damaged starch, however it may increase the gelatinization degree and improve the stretchability of rice noodles (Y. Liu, 1994; Nishita & Bean, 1982).

2.1.3.2 Extrusion cooking process

Recently, the high-temperature extrusion has become widely used for manufacturing starch-based foods, including starch noodles (e.g. rice noodles) (N. Wang et al., 2014; F. Wu et al., 2015). Extrusion processing is a high temperature and short time method for making food products (N. Wang, Maximiuk, & Toews, 2012). This process allows starch gelatinization, protein denaturation, and restructuring of other extrudates that improve the texture and histology of the processed starch noodles. The extrusion process simplifies the traditional process by significantly saving energy, water and time (N. Wang et al., 2014; F. Wu et al., 2015). Specifically, the extrusion process avoids heating (steaming or boiling) the starch noodles in boiling water before the cooling and drying step (N. Wang et al., 2012).

Although, the internal structure of extrusion machine is simple, complex changes of RF are taking place in the extrusion cavity, such as Maillard reaction, protein denaturation, enzyme inactivation and starch gelatinization. Many factors influence these changes such as the extrusion cavity temperature,
material moisture content and the duration in the extrusion cavity (Chuang & Yeh, 2004; Deng, Lin, & Jin, 2004; Gao, 2006; Guha, Ali, & Bhattacharya, 1997). Moreover, it was reported that the molding configuration of extruder plays an important role in impacting the quality of rice noodles. For example, when the hole number is large, the cavity pressure drops, which might affect the gelatinous structure of rice noodles, or cause discontinuity during extrusion, and result with uneven thickness of final products.

Besides, the screw speed determines the rice noodle qualities as well. The output of rice noodles will raise followed with the improvement of the screw speed. However, it is difficult to feed the food material with high screw speed, which could decrease the quality of rice noodles (W. Zhao, 2008). The extruder molding board diameter has noticeable influences on the water absorption and cooking property of rice noodles. When the diameter is between 0.8-1.2 mm, the quality of rice noodles is not impacted significantly, but the cooking loss will increase along with the decrease of the aperture. When the diameter is 0.6 mm or lower, water absorption time and cooking weight of cooked rice noodles are reduced, and there is an increase in break rate of cooked rice noodles (Liang, Zhao, Chen, & Ning, 2008).

On the other side, the cooking and processing method could vary the GI value of the food (Lin, Wu, & Lin, 2010). Cooked rice noodle usually has a moderate low GI value (~60), not like most of the cooked white rice varieties that have high GI values (above 80) (Lok et al., 2010). This difference in GI related to the extrusion process that allows reduction of molecular weight of starch granules, including amylose and amylopectin, which produced shorter starch branches that formed indigestible cross-link complexes, thus lowered the GI (Politz, Timpa, & Wasserman, 1994; Theander & Westerlund, 1987).

2.1.3.3 Retrogradation process

In rice noodle manufacture, it is typical to have the rice noodles air-cooled (retrogradation process) immediately after extrusion. Research has shown that retrogradation conditions such as temperature and humidity have a certain influence on the retrogradation speed and degree of rice noodles (Fan & Marks, 1998; Klucinec & Thompson, 1999; Leloup, Colonna, & Buleon, 1991; Perez, Villareal, Juliano, & Biliaderis, 1993). In China, the production of rice noodles typically allows 4-8 h or overnight
retrogradation time after extrusion at room temperature (~20°C), followed by placing them in steam pressure kettle for retrogradation again before drying and packing. The production of rice noodles in other countries is always by directly placing the noodles in steam pressure kettle after extrusion, and followed by 6-8 h or longer retrogradation. Thus, the rice noodles from China have better hardness and longer rehydration time (Cen, 2008). The optimum conditions of rice noodles retrogradation were at 45°C for 4-6 h. Compared to the air-cool at room temperature for retrogradation, this method is much more time efficient (Fu, 2007).

2.3 Pulses

Pulses are the consumable seeds of leguminous crops, including beans, peas, lentils and chickpeas (Tosh & Yada, 2010). Lately, there has been increasing interest in developing technologies to expand the application of pulses in processed food products, due to greater awareness of the various beneficial physiological effects for human health associated with the intake of pulses (Boye et al., 2010). These legumes contain high contents of protein (ranging from 17-30%), dietary fiber (DF) (ranging from 15-30%), starches, vitamins, minerals, and other important nutrients including carotenoids and isoflavones (Boye et al., 2010; Chung, Liu, Hoover, Warkentin, & Vandenberg, 2008; Tosh & Yada, 2010; B. Zhang et al., 2015). The yellow (with green hull) and red cotyledon are the two frequent lentil (Lens Culinaris L.) crops grown in Saskatchewan, Canada. Desi and Kabuli are the two major chickpea (Cicer arietinum L.) crops grown in Saskatchewan, Canada (Boye et al., 2010; Chung, Liu, Donner, et al., 2008; Chung, Liu, Hoover, et al., 2008).

Many researchers have shown consumption of pulses is associated with lowering the risk of cardiovascular disease, cancer, aging and type II diabetes (Dahl, Foster, & Tyler, 2012; Jukanti, Gaur, Gowda, & Chibbar, 2012; Veenstra et al., 2010). Also, according to the American Diabetes Association, consumption of pulses can be beneficial for weight control, which is highly recommended for overweight or obese individuals who have diabetes or are at risk of developing diabetes (Papanikolaou & Fulgoni III, 2008). Following are the in-depth analysis of beneficial characteristics of pulses, in particular lentil and
chickpea, as well as their application in foods.

2.3.1 Pulse starches

Starch is one of the major constituents within pulses. However, the starch content of pulses is not as high as cereal grains (such as rice) and ranges from 35 to 60% of the total constituents. Particularly, the total starch contents of chickpea varieties range from 29.1% to 46.0%, respectively. The total starch content of lentil varieties ranges from 46.0% to 52.1% (Dalgetty & Baik, 2003; Hoover, Hughes, Chung, & Liu, 2010). Chickpea usually contains a lower total starch content as compared with lentils, and significantly lower than cereal such as wheat or rice (Jukanti et al., 2012). Pulse starches usually have the granule size ranging from 0.4 to 103 µm with various shapes, including oval, spherical, round, elliptical, disks or irregular (L. Kaur, Singh, & Sodhi, 2002; J. Singh & Singh, 2001; N. Singh, 2011). Chickpea starch granule usually is oval shaped with a size ranging from 20 to 35 µm, while lentil starch granules are ellipsoid shaped with a size ranging from 10 to 30 µm (N. Singh, Nakaura, Inouchi, & Nishinari, 2008; N. Wang & Daun, 2004). Research has shown that pulse starch granules exhibit the type C X-ray diffraction pattern. The arrangement of the amylopectin double helices defines the characteristics of type C X-ray diffraction pattern (Sandhu & Lim, 2008; N. Singh et al., 2008). The proportions of long chain amylopectin are associated with the variation in crystallinity among different pulse starches. There is a high amount of amylose contained in pulse starches. Yet, the range of amylose content is wide and often depends on the variety of pulses (N. Singh et al., 2008). The amylose contents of the isolated yellow and red lentil starches range from 23.5 to 32.2%, whereas the amylose contents of the isolated chickpea starches range from 28.3% to 52.8% (Hoover et al., 2010; N. Singh, Kaur, Isono, & Noda, 2010).

During gelatinization, starch granules tend to swell and increase solubility because of the disruption of crystalline structure and Hydrogen bonding (N. Singh, Sandhu, & Kaur, 2004). Lentil has been known to have higher water binding capacity among all other pulse flours, (Chung, Liu, Hoover, et al., 2008). The swelling power of lentil starches is in the range of 16-20g g⁻¹ (N. Singh, 2011) in comparison to 11.4-13.6 g g⁻¹ of chickpea starches (N. Singh et al., 2004). Pulse starches have restricted swelling and low solubility,
which is indicative of a strong orderly arrangement of polymer chains allowing maximum interaction via hydrogen bonding within the starch granules. The initial restricted swelling and solubility of pulse starches are primarily attributed to their high amylose content, since after the leaching of amylose, both the swelling power and solubility of starches are increased (N. Singh, 2011). As a result, pulse starches have a stronger gelling ability compared to rice starch, which is necessary for various food products.

Gelatinization properties of chickpea and lentil starch and flour are displayed in Table 1. The pasting properties of PT, PV, SBV, FV of some varieties of Canadian lentil and chickpea flour ranged from 70.0 to 71.1 and 69.1 to 71.8 °C, 1185 to 1359 and 755 to 1347 cP, 605 to 662 and 320 to 610 cP, 1651 to 1781 and 1068 to 1938 cP, respectively (Chung, Liu, Hoover, et al., 2008). The BDV ranged from 140 to 239 cP for lentil flour, but not determined for chickpea flour. In general, the chickpea flour has lower PV, SBV, BDV, FV and higher PT than lentil flour was attributed to chickpea flour having higher free fatty acid and existence of more amylose-lipid complexes than lentil flour. But, the major reason for pulse flour having lower gelatinization properties and higher gelatinization temperatures than cereal grains (i.e. rice) is due to chickpea flour containing lower starch content than cereal grains with the presence of dietary fiber and protein, which results in decreasing the percentage of amylose content of the total constituents (Chung, Liu, Hoover, et al., 2008). Moreover, researchers have shown that different pulse starches have different retrogradation tendency. Both amylose content and long branch chain amylopectin have effects on retrogradation (N. Singh et al., 2008), which allow isolated pulse starches with higher amylose to be retrograded to a greater extent as compared with cereal starches (Hoover et al., 2010). However, when processing in flour form, chickpea and lentil flour retard retrogradation in comparison with RF, which is attributed to its lower starch content and higher content of dietary fiber and protein (Chung, Liu, Hoover, et al., 2008; F. Wu et al., 2015).

Chickpea flours contain an excessive amount of slowly digestible starch and lower amount of resistant starch content than other pulse flours. The in vitro starch digestion of some Canadian chickpea and lentil flours contained 7.6 to 7.8% and 9.4 to 12.4% of RDS, 23.7 to 24.7% and 27.1 to 30.7% of
SDS, as well as 14.4 to 14.9% and 3.1 to 6.4% of RS, respectively (Chung, Liu, Hoover, et al., 2008). Furthermore, processing might decrease the RS content of the material. Research indicated that the raw material of chickpea and lentil showed slightly higher RS (3.39 and 3.25 g/100 g, respectively) as compared with freeze-dried cooked (2.23 and 2.46 g/100 g, respectively) chickpea and lentils (de Almeida Costa, da Silva Queiroz-Monici, Reis, & de Oliveira, 2006). Evidence suggested that RS occupies 35% of total chickpea starch and contains a higher ratio of amylose than most wheat or rice varieties (Jukanti et al., 2012). However, lentil flour had the lowest GI (< 55) compared with other pulse flours (Asif, Rooney, Ali, & Riaz, 2013). Furthermore, as mentioned in Section 2.1.5, amylose has a significant negative correlation with pGI. Researchers have reported that lentil with slightly higher amylose content than chickpea resulted in lower predicted GI value, which ranged from 41.4 to 41.5 for lentil flour and 48.9 to 56.1 for chickpea flour (Chung, Liu, Hoover, et al., 2008).

Table 1. Gelatinization properties of starches and flours from various chickpea and lentil cultivars.

<table>
<thead>
<tr>
<th>Name</th>
<th>T_r (˚C)</th>
<th>T_p (˚C)</th>
<th>T_c (˚C)</th>
<th>ΔH (J/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lentil flour^a</td>
<td>67.3 - 68.4</td>
<td>75.6 - 76.1</td>
<td>~82.0</td>
<td>3.0 - 3.2</td>
</tr>
<tr>
<td>Chickpea flour^a</td>
<td>60.1 - 60.8</td>
<td>70.3 - 72.5</td>
<td>80.1 - 81.5</td>
<td>4.3 - 5.1</td>
</tr>
<tr>
<td>Lentil starch^b</td>
<td>57.8 - 68.4</td>
<td>66.0 - 76.1</td>
<td>71.0 - 85.0</td>
<td>3.0 - 13.5</td>
</tr>
<tr>
<td>Chickpea starch^b</td>
<td>57.7 - 60.25</td>
<td>66.2-68.6</td>
<td>76.1 - 79.9</td>
<td>2.6 - 14.2</td>
</tr>
</tbody>
</table>

^a retrieved from Chung, Liu, Hoover, et al. (2008)
^b retrieved from Chung, Liu, Donner, et al. (2008); Hoover and Ratnayake (2002); N. Singh et al. (2008)

2.3.2 Dietary fiber

Pulses are rich in dietary fiber (DF). DF is a nutritional element that has beneficial effects on human health (Piwińska, Wyrwisz, Kurek, & Wierzbicka, 2015). DF is a highly complex carbohydrate polymer with ten or more monomeric units, which comes from edible plants. They resist digestion in the small intestine, yet are fermentable by colonic microflora locating in the large intestine (Phillips & Cui, 2011). DF has three major beneficial properties: 1) decreases transit time within the intestine; 2) reduces total and LDL cholesterol levels; 3) lowers postprandial blood glucose or insulin levels. TDF is composed of soluble and insoluble dietary fiber. Insoluble dietary fiber (IDF) consists of three major polymers:
cellulose, hemicellulose, and lignin (Chawla & Patil, 2010). Cellulose is defined as β-(1→4)-D-Glc homopolymer with extensive hydrogen bonding, whereas hemicellulose is composed of heteropolymers of pentoses (i.e. xylose and arabinose), hexoses (i.e. glucose, galactose, mannose) and sugar acids (i.e. acetic acid). Lignin is a heteropolymer bound with cellulose that is extremely resistant to digestion (Lunn & Buttriss, 2007). IDF is not digested in the stomach and the intestines, but it absorbs water and binds organic toxins and waste (Tosh & Yada, 2010). IDF is responsible for gut transit time, which helps in constipation and digestive health (Weickert & Pfeiffer, 2008).

Soluble dietary fiber (SDF) is composed of some hemicelluloses, pectins, gums, mucilages and storage polysaccharides (Cappa, Lucisano, & Mariotti, 2013; Chawla & Patil, 2010; Lunn & Buttriss, 2007). Researchers have reported that consuming SDF helps regulate postprandial glucose responses and decreases blood cholesterol levels, thus leading to prolonged gastric emptying and reducing the risk of colorectal cancer and cardiovascular disease (Piwińska et al., 2015; Tosh & Yada, 2010; Weickert & Pfeiffer, 2008).

Pulse hulls contain a high amount of DF, 75% in chickpeas hulls and 87% in lentil hulls from dry mass (DM) (Dalgetty & Baik, 2003). In particular, lentils contain no cholesterol, limited saturated fat and a low amount of sugar, but a high amount of DF (Asif et al., 2013). Tosh and Yada (2010) concluded that the TDF content of lentils (L. culinaris) ranged from 18 to 22 g/100 g DM, with 11 to 17 g/100 g DM of IDF and 2-7 g/100 g DM of SDF. TDF content of some Canadian chickpea varieties ranged from 18 to 22 g/100 g DM, with 10 to 18 g/100 g DM of IDF and 4 to 8 g/100 g DM of SDF (Jukanti et al., 2012). In general, chickpea has a higher or equal amount of TDF in comparison with lentils. Desi chickpea contains a higher TDF and IDF than Kabuli, since the Desi type has a thicker hull compared with Kabuli chickpea.

However, there is no noticeable difference in SDF between Desi and Kabuli chickpea, because similar amount of hemicellulose (found ~55% of total chickpea seed dietary fiber) presents within both chickpea types (Jukanti et al., 2012). With regards to monosaccharide composition, glucose is mainly contained in the hull and insoluble fiber fractions of chickpea and lentils. Xylose is only present in the
soluble fiber fraction of chickpea, while xylose is contained in the hull and IDF fraction of lentil. Galactose and cellobiose only appear in SDF fraction of chickpea and lentils. Lastly, the hemicellulose sugar arabinose/rhamnose are contained in the hull and insoluble fiber fraction of chickpea, but only present in insoluble fiber fraction of lentil (Dalgetty & Baik, 2003).

The high complex carbohydrates and dietary fiber diet obtained from pulses permit slow digestions and provide a feeling of satiety, increases stool volume and colon transit time. There is evidence to suggest that consuming pulse could improve bowel function and satiety (FAO, 2016). The DF also acts to bind toxins and cholesterol in the gut, thus allowing the removal of these substances from the body, which could reduce the risk of associated heart diseases and blood cholesterol level. Also, high iron level possessed within pulses helps transport oxygen throughout the body, which boosts energy production and metabolism. Literature has shown that many nutrients and non-nutrient substances of pulses are associated with reducing the risk of cancer and cardiovascular diseases (CVD) and diabetes (Dahl et al., 2012).

Furthermore, high dietary fiber-containing (including high resistant starch content) foods such as pulses, including chickpeas and lentils, usually have GI values lower than 55. Therefore, consuming pulses regularly will be beneficial for people with diabetes, because it could reduce blood lipid levels and slow down the glucose released into the blood, with balanced insulin response. Also, RS contained in pulses aids in increasing glucose tolerance and insulin sensitivity, which is particularly beneficial for type II diabetes patients (D. J. Jenkins, Kendall, Augustin, & Vuksan, 2002). Low GI-diet also aids in weight management, preventing obesity by increasing chewing time and satiety. Type II Diabetes patients with intakes of 1 cup/day of cooked beans, chickpea or lentils flours showed a higher reduction of blood pressure (-0.8%) and heart rate compared with the patients with wheat fiber diet. Besides, there was a 2.7 kg decrease in body weight, 1.4 cm reduction in waist circumference and 8 mg/dL reduction of total cholesterol (Mudryj, Yu, & Aukema, 2014). As a result, with high dietary fiber, pulses have great potential to be applied as natural health ingredients for functional food products.
2.3.3 Protein

Pulses also contain an excessive amount of protein, ranging from 17% to 30% (Boye et al., 2010). The storage protein globulins and albumins are the two major protein groups within pulses. Globulins are usually multi-subunit molecules with high molecular weight. The two major globulin components in pulses are legumin (11S) and vicilin (7S) (Dziuba et al., 2014). Opposite to globulins, albumins are composed of relatively low to medium molecular weight molecules with hydrophilic surfaces, which allows them to be soluble in water. Also, albumins mainly contain enzymatic proteins, enzyme inhibitors, and lectins. The minor protein groups that exist in pulses are prolamins and glutelins (Boye, Zare, & Pletch, 2010). Prolamin is soluble in alcohol and mainly contains proline and glutamine. Glutelins are storage proteins that are acid or alkali soluble and contain more methionine and cysteine than globulins, but this is yet a minuscule percentage of total protein content in pulses.

The protein contents for lentil flours range from 26.8 to 31.5% (Chung, Liu, Hoover, et al., 2008; Dalgetty & Baik, 2003). Specifically, the total protein content of lentil includes 16.8% albumins, 44.8% legumins, 4.2% vicilin, 11.2% glutelins and 3.5% prolamins (Boye, Zare, & Pletch, 2010). Also, Boye et al. (2010) stated that all the protein fractions were glycosylated, including vicilin containing approximately 2.8% carbohydrate. The protein content of chickpeas varies significantly from 17 to 22% before and 25.3 to 28.9 after dehulling, respectively (Jukanti et al., 2012). Chickpea flour has protein content approximately around 24% of the total component (Asif et al., 2013). Usually, Desi chickpea has higher protein content than Kabuli chickpea, but smaller in size. The chickpea protein shows higher nutritional value than peas and lentils. The total protein content includes 16.18% albumins, 41.79% legumins, 9.99% glutelins and 0.48% prolamins (da Silva, Neves, & Lourenço, 2001). In general, chickpea flour has a higher amount of fat and DF, as well as a relatively lower protein content compared to peas and lentils (Asif et al., 2013; Jukanti et al., 2012).

2.3.3.1 Amino acid profile

There are 20 amino acids (AA) commonly occurring in food proteins divided into two categories:
essential and non-essential amino acid (NEAA). The essential amino acids (EAA) are the AA that human body cannot synthesize by itself, including lysine, methionine, threonine, valine, isoleucine, leucine, phenylalanine, histidine, and tryptophan. The non-essential amino acids are the ones that can naturally occur in the human body, including alanine, arginine, asparagine, aspartic acid, glutamic acid, cysteine, glutamine, glycine, proline, serine, and tyrosine. In general, commonly consumed pulse proteins including those from chickpea and lentils have limited sulphur containing amino acids (cysteine and methionine) and tryptophan, but considerable amounts of lysine, leucine, aspartic acid, glutamic acid and arginine (Boye et al., 2010; Jukanti et al., 2012) (Table 2). There is no significant difference between Canadian Desi and Kabuli chickpeas, and a slight difference in comparison with Canadian green lentils for their amino acid profiles. Chickpeas and lentils usually have ~1.22 g/10 g N of methionine and cystine, which is very low compared with cereal grains (N. Wang & Daun, 2004). The deficiencies of sulfur containing AA in pulses could be minimized by combining processed foods that contain excessive cysteine, methionine, and tryptophan (i.e. rice), which will offer balanced essential amino acid profile (Boye et al., 2010; Carvalho et al., 2013; Jukanti et al., 2012). Several food products, such as baked products, snack foods, pasta, and starch noodles, have successfully used pulses as an ingredient for improving their nutritional values (Asif et al., 2013).
Table 2. Amino acid content in Canadian chickpeas and green lentil in comparison to white rice.

<table>
<thead>
<tr>
<th>Amino acids</th>
<th>Chickpea (Kabuli)(^a) (g/16g N)</th>
<th>Chickpea (Desi)(^a) (g/16g N)</th>
<th>Green Lentils(^a) (g/16g N)</th>
<th>Rice(^b) (g/16g N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lys</td>
<td>4.9-6.70</td>
<td>5.2-6.90</td>
<td>4.4-7.00</td>
<td>3.41</td>
</tr>
<tr>
<td>Met</td>
<td>1.1-2.10</td>
<td>1.1-1.70</td>
<td>0.8-1.20</td>
<td>2.62</td>
</tr>
<tr>
<td>Cys</td>
<td>0.8-2.00</td>
<td>1.1-1.60</td>
<td>0.7-1.40</td>
<td>1.92</td>
</tr>
<tr>
<td>Phe</td>
<td>4.5-6.20</td>
<td>4.5-5.90</td>
<td>3.7-5.00</td>
<td>3.46</td>
</tr>
<tr>
<td>Tyr</td>
<td>2.2-3.30</td>
<td>1.4-3.10</td>
<td>1.2-3.40</td>
<td>4.32</td>
</tr>
<tr>
<td>Ile</td>
<td>2.6-3.90</td>
<td>2.5-4.40</td>
<td>2.6-4.20</td>
<td>4.89</td>
</tr>
<tr>
<td>Leu</td>
<td>5.6-7.20</td>
<td>5.6-7.70</td>
<td>5.7-7.10</td>
<td>8.24</td>
</tr>
<tr>
<td>Thr</td>
<td>3.3-5.10</td>
<td>3.7-4.70</td>
<td>3.6-4.90</td>
<td>4.20</td>
</tr>
<tr>
<td>Val</td>
<td>2.9-4.60</td>
<td>2.8-4.70</td>
<td>3.3-4.90</td>
<td>6.28</td>
</tr>
<tr>
<td>Arg</td>
<td>8.3-13.7</td>
<td>8.3-13.6</td>
<td>6.2-11.1</td>
<td>7.41</td>
</tr>
<tr>
<td>His</td>
<td>1.7-2.40</td>
<td>1.7-2.70</td>
<td>1.8-3.00</td>
<td>2.90</td>
</tr>
<tr>
<td>Ala</td>
<td>3.5-4.70</td>
<td>3.6-4.53</td>
<td>3.6-4.30</td>
<td>4.64</td>
</tr>
<tr>
<td>Asp</td>
<td>11.2-12.9</td>
<td>11.1-15.9</td>
<td>10.1-15.9</td>
<td>4.88</td>
</tr>
<tr>
<td>Glu</td>
<td>13.1-17.5</td>
<td>13.4-18.7</td>
<td>12.8-17.3</td>
<td>7.71</td>
</tr>
<tr>
<td>Gly</td>
<td>3.2-4.50</td>
<td>3.3-4.20</td>
<td>3.3-4.40</td>
<td>4.21</td>
</tr>
<tr>
<td>Pro</td>
<td>3.8-6.50</td>
<td>4.0-6.30</td>
<td>3.5-6.10</td>
<td>3.68</td>
</tr>
<tr>
<td>Ser</td>
<td>5.2-6.70</td>
<td>5.5-6.90</td>
<td>5.0-6.30</td>
<td>3.79</td>
</tr>
<tr>
<td>Trp</td>
<td>0.7-1.60</td>
<td>0.8-1.10</td>
<td>0.9-2.60</td>
<td>1.32</td>
</tr>
<tr>
<td>Cys + Met</td>
<td>1.9-4.10</td>
<td>2.2-3.1</td>
<td>1.6-2.60</td>
<td>4.54</td>
</tr>
<tr>
<td>Tyr + Phe</td>
<td>6.7-9.20</td>
<td>6.6-8.7</td>
<td>5.4-8.20</td>
<td>7.78</td>
</tr>
</tbody>
</table>

\(^a\)retrieved from N. Wang and Daun (2004)

\(^b\)retrieved from Shekib, Zoueil, Youssef, and Mohamed (1986)

2.3.4 Micronutrients and antioxidants

Pulses are also a rich source of micronutrients, including a high level of selenium, thiamin, niacin, folate, riboflavin, saponins and pyridoxine (Tiwari, Gowen, & McKenna, 2011). Specifically, chickpeas contain the right amount of thiamin, niacin, calcium, phosphorus, iron, magnesium and potassium. Lentils are a rich source of iron, phosphorous, thiamine, vitamins B, and C, folic acid and antioxidants (Asif et al., 2013). Phenolic compounds with nucleophilic characteristics have been positively correlated with antioxidant activities, such as inhibition of lipid peroxidation by scavenging free radicals and avoiding free radical damage (Padhi, Liu, Hernandez, Tsao, & Ramdath, 2016). Natural antioxidants
from plant sources can act as protective factors against oxidative stress caused by free radicals that disturb the normal redox state within the human body (Kan, Nie, Hu, Liu, & Xie, 2016). Polyphenol antioxidants that are derived from some food components can donate electrons to free radical molecules, thereby preventing oxidative damage and cell apoptosis. Thus, natural antioxidants may avoid the chance of getting chronic diseases, such as cancer, cardiovascular diseases, obesity, and cataracts (Gujral, Angurala, Sharma, & Singh, 2011; Kan, Nie, Hu, Liu, et al., 2016).

Pulses is a useful source of phenolic compounds, which provide valuable sources of antioxidants in the human diet, in addition to their unique dietary fiber and protein contribution to human health (Mudryj et al., 2014; Padhi et al., 2016). Lentils have the highest phenolics/flavonoids, followed by beans among four major pulses: peas (green and yellow), lentils, chickpeas and beans (black and red kidney) Xu and Chang (2007). Lentils and chickpeas exhibit total phenolic content (TPC) of 6.56 and 1.81 mg gallic acid equivalents g⁻¹ and total flavonoid content of 1.30 and 0.18 mg catechin equivalents g⁻¹, respectively. However, many factors affect the antioxidant activity of the pulses, such as varieties, geological locations, and method of determination. Researchers have been pointed out that green lentils contained the highest TPC of 7.45 mg GAE/g for Laird and 7.30 mg GAE/g for Easton among all the four common Canadian pulses (2 peas, lentils, beans, and chickpeas) and were noticeably higher than red split lentils, which provide 1.22 mg GAE/g. Furthermore, Desi chickpea contains higher TPC of 2.78 mg GAE/g for CDC Consul and 2.87 mg GAE/g for CDC Cozy, in comparison with Kabuli chickpea of 1.57 mg GAE/g for CDC Frontier and 1.47 mg GAE/g for CDC Leader (Padhi et al., 2016).

There are three standard methods being developed for measuring antioxidant activity in pulses: ferric reducing antioxidant power (FRAP) assay, 2-2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activities, and oxygen radical absorption capacity (ORAC) tests (Giusti, Caprioli, Ricciutelli, Vittori, & Sagratini, 2017). The DPPH radical scavenging assay was developed by Blois (1958) with DPPH act as a stable free radical to measure the scavenging capacity of antioxidants in it. It has been shown as a rapid, simple inexpensive and commonly used in vitro method for measuring antioxidant
As a stable free radical, DPPH delocalizes spare electrons over the molecule, which prevents the molecule from dimerizing (Figure 2). When DPPH is in ethanol solution, the delocalization of electrons induces a dark violet colour measured at around 517 nm. Mixing DPPH with a substance (e.g. antioxidants) that can donate a hydrogen atom, which leads to its reduced form, with the disappearance of the violet colour (Figure 2) (Alam, Bristi, & Rafiquzzaman, 2013). FRAP assay was based on measuring the capability of antioxidant to reduce ferric iron (Benzie & Strain, 1999). At low pH, the antioxidant can reduce complex of ferric iron and 2,3,5-triphenyl-1,3,4-triaza-2-azoniacyclopenta-1,4-diene chloride (TPTZ) to the ferrous form. This reduction can be observed at around 593 nm (Alam et al., 2013).

Colour of pulse seeds can be a good indicator of their phenolic content and antioxidant activities. Researchers found that darker coloured coats of pulses positively correlated with TPC and their antioxidant activities (Rocha-Guzmán et al., 2007; Xu & Chang, 2007). Hulled pulses contained higher TPC than dehulled pulses, indicating most of the TPC is present in the hull of pulses. For example, TPC of nine lentil varieties ranged from 0.84 to 4.52 mg of GAE/g with black lentil having the highest and dehulled red lentils possessing the lowest value of TPC (Giusti et al., 2017). Their corresponding DPPH inhibition ranged from 39.2 to 92.5% with black lentils having the most and dehulled lentils having the weakest inhibition activity. Furthermore, chickpea varieties had TPC ranging from 0.72 to 1.2 mg GAE/g with highest for black chickpeas and lowest for Desi chickpea, while the contributed DPPH inhibition activity ranged from 25.5 to 64.9% according to their TPC content (Giusti et al., 2017). Gujral et al. (2011) concluded that cooking decreased the TPC by 10 to 45% and reduced the antioxidant activity by 27 to 68%. Cooking will cause leaching of soluble antioxidants in water, which could explain the decrease in TPC (Gujral et al., 2011; Xu & Chang, 2007).

Figure 2. DPPH radical scavenging activities mechanism (Alam et al., 2013).
2.3.5 Other minor components

Some minor components in pulses are fat, vitamins, and minerals, such as iron, zinc, and copper (Mudryj et al., 2014; S. Wang, Melnyk, Tsao, & Marcone, 2011). Pulses contain a fair amount of vitamins such as pyridoxaine, pyridoxal, pyridoxine. Research indicated lentil and chickpea had 63.3 and 26.9 µg/100 g DM of pyridoxaine, 94.2 and 74.8 µg/100 g DM of pyridoxal and 44.2 and 23.5 µg/100 g DM of pyridoxine, respectively. Pulses have a good amount of zinc, copper and calcium; lentil usually has slightly higher content (2-10 µg/100 g DM) of these minerals than chickpea. Notably, zinc corresponds to reducing oxidative stress in cell and increasing immune cell function (Ibs & Rink, 2003; Mudryj et al., 2014).

In addition, the fat content of pulse seeds ranges from 2-21%. Fat of pulses are mostly (~60%) composed of exogenic unsaturated fatty acids (linoleic and linolenic) (Oomah, Patras, Rawson, Singh, & Compos-Vega, 2011). Although chickpeas have higher fat content (3-5%) than some pulses including pea and lentil, mostly they are composed of polyunsaturated fatty acids, and only less than 1% of saturated fatty acid (Asif et al., 2013). There is increasing evidence to suggest that consumption of pulses regularly could lower the risk of cardiovascular disease by influencing the blood pressure, platelet activity, lipid profiles, and inflammation. The mono- and polyunsaturated fat and plant sterols contained in pulses aid in enhancing high-density lipoprotein (HDL) cholesterol, meanwhile reducing low-density lipoprotein (LDL) and total cholesterol (Mudryj et al., 2014), as well as lower heart disease associated inflammatory biomarkers (Esmailzadeh & Azadbakht, 2012). Indeed, pulse consumption led to a reduction of fasting serum cholesterol, triacylglycerol and LDL cholesterol (Anderson & Major, 2002).

2.4 Application of pulse ingredients in rice noodles and pasta

There is increasing research associated with incorporating pulses into food products, to enrich their quality and nutrients, including applying pulses to make noodles or pasta. Research showed the addition of 5-30% green and yellow peas, lentil and chickpea flours into semolina increased cooking loss, firmness, pulse flavor, and colour intensity of spaghetti (Y. H. Zhao, Manthey, Chang, Hou, & Yuan,
The consumers preferred spaghetti without the addition of pulse flours, but they could accept 15% lentil or green pea substitution, and 20% chickpea or yellow pea substitution as well. Furthermore, there was another study that investigated the incorporation of 5-50% chickpea flours in durum lasagna (Sabanis, Makri, & Doxastakis, 2006). The results indicated the addition of chickpea improved the physical properties of the dough, but there was a decrease in processing, handling, and cooking of durum lasagna for the higher substitution of chickpea flours. The effects of incorporating 10% of four types of legume (mung bean, soya bean, red lentil, and chickpea) flour into semolina spaghetti were produced with improved nutrition values, including dietary fiber and protein (Chillo, Monro, Mishra, & Henry, 2010). The cooking quality was not affected by the 10% legume incorporation, but there was an increase in its GI as compared with the traditional semolina spaghetti. Therefore, there has not been any successful formulation for incorporating a large level of pulses into pasta with enriched nutrients, but without affecting its processing or cooking properties.

Lately, there has been growing interest in gluten-free noodles, mainly relating the approach of incorporation of pulse starch or flour into RF that could lead to improved quality, mouthfeel and acceptability (Rathod & Annapure, 2017; N. Wang et al., 2014; F. Wu et al., 2015). For instance, the addition of Mung bean starches up to 8% positively affected rice noodle quality including improved cooking (lower cooking time, cooking loss and break rate) and texture properties (increased firmness, elasticity, slipperiness and chewiness) (F. Wu et al., 2015). However, based on the comprehensive analysis of cost and quality of fortified rice noodles, 5% Mung bean starch substitution is the most efficient way to improve rice noodle quality. However, due to the high cost of mung bean starch, researchers have tried to substitute mung bean starch with other lower cost pulse starches. There was some success achieved using pea and lentil starches (N. Wang et al., 2014). Novel starch noodles showed less colour intensity, better firmness and superior textures compared with commercial mung bean starch noodles. However, there was a lack of a complete sensory test for the pea and lentil starch noodles to access the acceptance of consumers. The most recent research was to study the influences of blending lentil from 0 to 100% with...
rice on the qualities of noodles with increased fiber and protein content (Rathod & Annapure, 2017). The research suggested that 40% lentil substitution was most acceptable with better noodle quality among all other formulations.

Finally, incorporation of pulse flour into RF may improve the nutritional properties of gluten free rice noodles including enriched dietary fiber, protein, and balanced essential amino acid, with lower GI. Research has been done to fortifying gluten free spaghetti with 0%, 20% and 40% of bean flours (Giuberti et al., 2015). The novel spaghetti had higher protein, dietary fiber and resistant starch content, as well as showing a decrease in vitro GI, which were all nutritionally beneficial for human health. The addition of bean flours did not negatively affect the spaghetti texture properties and cooking loss, but there was an elevation in optimal cooking time and water absorption capacity. Overall, in the technology of rice noodles development, there have not been many studies that focus on investigating the effects of fortifying rice noodles with gluten-free Canadian pulse ingredients such as chickpea or lentil. Hence, the purpose of this research was to study the effects of adding Canadian lentil and chickpea flour on the nutritional characteristics and qualities of novel rice noodles.
Chapter 3. Materials and methods

3.1 Materials

Canadian green lentil and chickpea (Desi) flours were purchased from the local market and used throughout in this study for all novel rice noodle formulations. Three different types of Rice samples were purchased at Nanchang local market to investigate the formulation of rice noodles: Late harvested Indica rice (R1), early harvested Indica rice (R2) and Japonica rice (R3). All rice samples were ground into flour and went through 80 mesh sieves for standard particle size. The purchased flours were stored in airtight plastic containers under a 4°C moisture controlled fridge for further investigations. Commercial rice noodles (RN1) purchased from the local market at Nanchang were used as the first control.

3.2. Formulation of rice noodles

3.2.1 Determination of thermal properties

Thermal properties were investigated using a Q20 DSC analyzer (TA Instruments, New Castle, Delaware, USA). Each sample was prepared with a water-to-dry flour weight ratio of 2:1 and sealed into an aluminum pan. Then the samples were equilibrated overnight at room temperature. Gelatinization was characterized by measurement from 10 to 160°C at a heating rate of 10 °C/min. Thermal transitions for gelatinization were measured by onset temperature (To), peak temperature (Tp), conclusion temperature (Tc) and enthalpy of gelatinization (ΔH). All measurements were carried out in triplicate.

3.2.2 Determination of pasting properties

The pasting properties were measured by a Rapid Visco Analyzer (RVA-4, Newport Scientific, Warriewood, Australia) according to Yadav, Yadav, and Kumar (2011). A sample suspension (3.0 g, 14g/100 g moisture basis) was loaded into a RVA canister and distilled water was added into flour mixture samples giving the total weight of 28 g. The temperature profile was initiated from 50°C for 1 min followed by increasing the temperature to 95 °C in 7.5 min, holding the temperature for 5 min, then cooling to 50°C within 8 min, and staying at 50 °C for 2 min. The rotational speed was maintained at 160 rpm throughout the procedure. The pasting properties of flour mixtures were characterized by several
parameters, including peak viscosity (PV), final viscosity (FV), breakdown (BDV), setback (SBV) and pasting temperature (PT). All the measurements were conducted in triplicate.

### 3.2.3 Determination of amylose

The amylose content of raw pulses and rice samples were analyzed according to Yun and Matheson (1990) method using an amylose/amylopectin assay kit (Megazyme International Ltd, Wicklow, Ireland). The complete sample dispersing was carried out by heating sample in dimethyl sulphoxide (DMSO). The lipids in the sample were removed by adding 95% (v/v) ethanol into the solution and centrifuging to recover the precipitated starch (W. R. Morrison & Laignelet, 1983). Afterwards, the precipitated sample was dissolved by heating the sample in an acetate/salt solution (solution A), followed by the precipitation of the Amylopectin with the addition of lectin concanavalin A (Con A) solvent and removed by centrifugation. Then, the remaining amylose within the supernatant was hydrolyzed to D-glucose by the addition of amyloglucosidase/α-amylase enzyme. The total starch was measured by taking a portion of solution A and hydrolyzing to D-glucose. Both solutions (amylose and total starch) were added in glucose oxidase, peroxidase and 4-aminoantipyrine (GOPOD) to measure the absorbance at 510 nm. The amylose content was calculated by the absorbance of the supernatant of the ConA precipitated against the absorbance of the total starch sample. Thus, the amylose contents were presented as a percentage of amylose in total starch content of the raw samples. Then, the percentage of amylose content of the total constituent of tested flour samples were calculated by % of the amylose content in the starch times the percentage of the total starch content of corresponding flour samples determined in section 3.5.5.2. All the measurements were conducted in triplicate.

### 3.2.4 Preparation of rice flour mixtures

Based on the results of thermal properties, pasting properties, and amylose content of the three rice flour samples, the novel rice noodle formulation (RM) was prepared by mixing all three rice samples in a 1:1:1 ratio for better incorporation with pulses. The RM was blended with each individual pulse flours in the proportion of 100:0, 85:15, 70:30, and 50:50 to give pulse fortified rice noodle formulations according to
Table 3. The lentil flour had a coarser texture than chickpea flour because lentils had a thicker seed coat than chickpea, thus lentil flour substitutions were further investigated by letting the lentil flour pass through 80 mesh sieves for uniform size. The large particles of lentil flour that did not sieve through 80 mesh was defined as lentil (N), while the remaining lentil flour that did pass through 80 mesh was defined as lentil (F). Novel rice noodle samples were prepared with lentil (F) at 30% substitution level. Lastly, 0.25% of psyllium was added into 30% lentil flour substitution of rice noodle samples to investigate whether the addition of psyllium could improve the quality of novel lentil flour substituted rice noodles. Polyethylene bags were used for packing and sealing the prepared samples. All the flour samples were kept at 4°C in the moisture controlled environment for further analyses and use.

3.2.5 Rice noodle process

Nine 500 g (minimum amount to feed the machines) premixed flour mixtures for making novel rice noodles with different formulations were weighed separately (Table 3). For consistency of flour slurries to feed the machine, different water contents were added to corresponding solid flour mixtures according to Table 3. The prepared slurries were heated and extruded through the rice noodle extruder machine SZ-30 with a boiling water jacket (Guangzhou XuZhong Food Machinery Co., Ltd., Guangzhou, China). The rice noodle extruder was set at 3 kw in power, 600 rpm/min in rotation speed, and average 150 g/min in extrusion feed rate. The extruded rice noodles were air dried overnight at room temperature, followed by heating at 70 °C. The final dried rice noodle had moisture contents between 8-11.5% w/w. Lastly, the dried rice noodle samples were packed in polyethylene bags and kept at 4°C in the moisture controlled environment for further analyses.
Table 3. Rice noodle formulations.

<table>
<thead>
<tr>
<th>Pulse flour</th>
<th>Amount of added water(^a)</th>
<th>Ratio of rice: pulse flour mixture</th>
<th>Symbol of formulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>500</td>
<td>100:0</td>
<td>RN2</td>
</tr>
<tr>
<td>Chickpea Flour</td>
<td>475</td>
<td>85:15</td>
<td>C15:R85</td>
</tr>
<tr>
<td>Chickpea Flour</td>
<td>475</td>
<td>70:30</td>
<td>C30:R70</td>
</tr>
<tr>
<td>Chickpea Flour</td>
<td>475</td>
<td>50:50</td>
<td>C50:R50</td>
</tr>
<tr>
<td>Lentil Flour</td>
<td>525</td>
<td>85:15</td>
<td>L15:R85</td>
</tr>
<tr>
<td>lentil (F)</td>
<td>525</td>
<td>70:30</td>
<td>L30(F):R70</td>
</tr>
<tr>
<td>Lentil Flour</td>
<td>525</td>
<td>70:30</td>
<td>L30:R70</td>
</tr>
<tr>
<td>Lentil Flour with psyllium</td>
<td>650</td>
<td>70:29.75:0.25(psyllium)</td>
<td>L30(P):R70</td>
</tr>
<tr>
<td>Lentil Flour</td>
<td>525</td>
<td>50:50</td>
<td>L50:R50</td>
</tr>
</tbody>
</table>

\(^a\) g in 500 g dry flour mixtures

3.3 Characterization of cooked rice noodles

3.3.1 Thermal properties of cooked rice noodles

The extruded rice noodles were measured with DSC to study the degree of gelatinization (DG%) which could be calculated by the following equation (L. Zhu et al., 2016)

\[
DG(\%) = \left( \frac{\Delta H_0 - \Delta H_1}{\Delta H_0} \right) \times 100
\]

Where \(\Delta H_0\) is the gelatinization enthalpy (J/g) of raw rice noodle flour samples blended with various ratios of pulse flours, and \(\Delta H_1\) is the enthalpy of extruded rice noodles (J/g) according to the results of Section 3.2.1. A 100% degree of gelatinization indicated completed cooked starch materials, where 0% indicated raw starch materials. All measurements were measured in triplicate.

3.3.2 Cooking properties

15 g of rice noodles were put in 200 mL of boiled distilled water in a beaker enclosed with aluminum foil to prevent evaporation losses. The noodle was defined as cooked if the white core in the noodle strand was disappeared. The cooking time was defined as the time used to reach this point for every rice noodle sample. The water absorbed by noodles during cooking was noted as cooked weight. The cooked rice noodle was rinsed with cold water (4 °C) and dried for 5 min before measuring the cooked weight. The cooked weight was measured by calculating the difference between cooked and dried rice noodles. The measurement of cooking loss was achieved by drying the cooking and cooling water at 120 °C overnight.
which the residues within the beaker reached a constant weight, which was the dry weight of solid remain in the beaker after the water evaporation. The sample was cooled to room temperature in a desiccator before weighted, to determine the actual solid loss. The cooking loss was expressed as the following ratio:

\[
\text{Cooking loss} = \frac{\text{dry weight of lost residues during cooking}}{\text{dry weight of uncooked rice noodles}}
\]

### 3.3.3 Texture profiles

The texture of rice noodles was measured on a texture analyzer (TA-XTplus; Stable Micro Systems, Surrey, UK) according to Han et al. (2011), with slight alternation with the method. In summary, a cylindrical probe (p/2) was used to compress a cooked rice noodle strand until reaching 75% of compression ratio at a 1.0 g of force. The compression test, pretest, and post-test speeds were 0.50, 0.50 and 1.00 mm/s, respectively. The distance was 10.0 mm and 5.0s was waited between each compression. The texture analysis (TPA) included hardness (maximum height of the peak), adhesiveness (calculated negative area of the 1st compression), cohesiveness (proportion of the area under the 2nd peak versus the area under the 1st peak), springiness (proportion of the distance measured during the 2nd compression versus the one measured during 1st compression), and chewiness (hardness * Cohesiveness * Springiness) of texture profile analysis (TPA) (Friedman, Whitney, & Szczesniak, 1963). The results were collected based on six replicates.

### 3.3.4 Colourimetric study of novel rice noodles

The Colour of the dried novel rice noodles was determined using a colourimeter (Monica Minolta, CR-10, Japan) according to B. Zhang et al. (2014). The tristimulus L*, a*, b* colour values were calibrated against a standard white plate and measured within an 8-mm diameter measuring area with diffuse illumination/viewing. The measurements were recorded as L*, the lightness of the sample ranging from the darkness at 0 to white at 100; a*, the redness when the value was positive and greenness when the value was negative; b*, the yellowness when the value was positive and blueness when the value was negative. The values were reported as the average of three independent measurements on the cooked novel rice noodles.
3.3.5 Nutritional characteristics

3.5.5.1 Protein content and amino acid composition

Protein was measured by the Dumas combustion method using a combustion nitrogen analyzer calibrated with EDTA (AOAC, 2000), and the protein content was obtained by N x 6.25. Amino acid compositions determined by an automatic amino acid analyzer (Hitachi L-8900, Japan). Briefly, 10 mg of each dried rice noodle sample was solubilized with 6 M HCl under a nitrogen atmosphere at 110 °C for 24 h. A pressure blowing concentrator was used to evaporating the hydrolysate, followed the sample was redissolved in water. Before injecting into the automatic amino acid analyzer, a 0.22 μm PTFE membrane was applied to filtering the sample. The EAA was calculated by the sum of lysine, methionine, threonine, valine, isoleucine, leucine, phenylalanine, histidine, and tryptophan measured. Total amino acid (TAA) was calculated based on the sum of all the amino acids measured. The values were reported as the average of three independent measurements.

3.5.5.2 Starch content

Total starch was determined using the total starch kit (Megazyme International, Wicklow, Ireland) according to standard AOAC method 996.11 (AOAC, 2000). Briefly, the dispersing of flour/noodle samples were carried out by the addition of 80% (v/v) ethanol. 2 M KOH was added to dissolve the resistant starch in an ice bath. Then, 1.2M sodium acetate solution (pH 3.8) neutralized the starch within the flour sample. The hydrolysis of the starches to form D-Glucose was done by addition of α-amylase and amyloglucosidase (AMG). Other constituents of the sample were removed by centrifugation and collection of the supernatant. Colourimetric reaction happened after addition of GOPOD reagent enzymes to the supernatant and was measured at 510 nm against reagent blank. The starch % was calculated based on the equation:

\[ \text{Starch, } \% = \frac{A F W}{V FV} 0.9, \]

Where A was the absorbance reading against the reagent blank, F was the conversion of D-glucose from absorbance to µg, W was the mg of the dry weight base sample measured.
Resistant starch (RS) and non-resistant starch (NRS) were measured using the Resistant Starch Kit (Megazyme International, Wicklow, Ireland) according to AOAC method 2002.02 (AOAC, 2005). Briefly, the flour/noodle samples were hydrolyzed to D-glucose with pancreatic α-amylase (10mg/mL) containing AMG (3 U/mL). To terminate the reaction and precipitate the RS, ethanol (99% v/v) was added into the solution and centrifuged. Then, the sample was washed twice with ethanol (50% v/v), followed by centrifugation for complete separation of RS and NRS. All the NRS (supernatants) were neutralized using sodium acetate buffer (pH 4.5). The solution was then mixed with diluted AMG (300 U/mL, diluted with 0.1 M sodium maleate buffer, pH 6.0) to hydrolyze NRS to D-glucose. For the measurement of RS, 2M KOH was added to dissolve the RS in an ice/water bath. 1.2 M sodium acetate buffer (pH 3.8) was added to neutralize the solution. RS hydrolyzed to D-glucose was done by addition of AMG (3300 U/mL) and was collected by centrifugation. For the measurement of both NRS and RS, GOPOD reagent enzymes were mixed with supernatant from the corresponding NRS and RS solution for colourimetric reaction and were recorded at 510 nm against reagent blank. RS/NRS content was calculated based on the equation: RS%/NRS= E*F/W*90.

Where E was the absorbance reading of either of RS or NRS solution against the reagent blank, F was the conversion of D-glucose from absorbance to μg, W was the mg of the dry weight base sample measured. The starches were reported as the average of three independent measurements.

3.5.5.3 Dietary fiber content

In general, dietary fiber was determined using a Total Dietary Fiber Kit (Megazyme International, Wicklow, Ireland). Particularly, the insoluble dietary fiber was measured after soluble dietary fiber was removed. The total dietary fiber was the combination of both insoluble and soluble dietary fiber (SDF), which was measured according to standard AOAC method 991.43 (AOAC, 2005). Briefly, duplicates of pre-weighed 1 g sample were suspended with 0.05 M MES-TRIS buffer (pH 8.2, 24°C). The gelatinization, hydrolysis and depolymerization of starches were carried out by heating the solution with heat-stable α-amylase at 100°C. Then, for solubilizing and depolymerizing the protein, protease was
added into the solution. pH was adjusted to 4.1 – 4.8 by adding HCl, followed by hydrolysis of starch to D-Glucose with AMG (pH 4.5). The mixture was filtered through a crucible and washed the remaining residue in the beaker with 78% ethanol, 95% ethanol and acetone. The crucibles with residue were dried and weighed, one duplicate was analyzed for protein and other one was analyzed for the ash content. The insoluble dietary fiber (IDF) was the weight of the residue after the deduction of protein and ash content measured. The filtrate collected was precipitated with 4 vol of 95% ethanol and the precipitate was allowed to form overnight at room temperature. Then, the solution was filtered through the crucibles again. Same as the determination of the IDF, the SDF content was the residuals weighed and the protein and ash content were deducted. The values were reported as the average of three independent measurements of the samples.

3.5.5.4 Moisture, Fat and Ash Content

Moisture content was determined by using 3 g of sample pre-weighed to a dish and placed in an oven drying at 105 °C for 3 h, followed by placing them in a desiccator for a constant weight according to AOAC official methods (AOAC, 2000). Lipid content was determined using Soxhlet apparatus with hexane as a solvent according to the method of Manirakiza, Covaci, and Schepens (2001). The ash content was determined according to AOAC official methods (AOAC, 2000), by weighing 5 g of sample into the crucible and placing it in the muffle furnace at 550 °C overnight. The furnace was turned off in the morning and the furnace was opened when the temperature inside the furnace was 120°C. The crucible was transfer to a desiccator to cool off to a constant weight and the remaining substances were weighed. All values were reported as the average of triplicates.

3.5.5.5 Total phenolic content (TPC) and total flavonoids content (TFC)

The extraction of phenolic compounds was carried out according to Kan, Nie, Hu, Wang, et al. (2016) with slight modifications. Briefly, 1 g of dried rice noodle samples was extracted with 50 mL of 80% ethanol-water (v/v). The extraction was carried out in darkness under an ultrasonic wave for 30 min at room temperature. Then it was centrifuged for 10 min at 4,500 g. The residue was re-extracted for 3
times and the supernatant from each extraction was collected. The combined supernatant was then evaporated under reduced pressure at 35 °C. After the drying step, the extract was re-dissolved in 10 mL ethanol and kept at -20°C for further analysis of total phenolic, flavonoids content and antioxidant activities. Each sample was extracted in triplicate.

The total phenolic content of the extracts was determined according to Folin-Ciocalteu’s method (Singleton, Orthofer, & Lamuela-Raventós, 1999) with slight modifications. The combination of 1 mL of the extracts or standard (gallic acid) and 1 mL of Folin–Ciocalteu reagent was left to react for 30 s. 3 mL of sodium carbonate solution, \( \text{Na}_2\text{CO}_3 \) (10 g/100 mL) were injected into the mixture to terminate the reaction. The extract mixture was left in the dark for 30 min at room temperature for the colour reaction, followed by measuring the absorbance at 764 nm. The standard curve was linear at a concentration ranging from 0.01 to 0.05 mg/mL of gallic acid equivalents. The phenolic content was expressed as mg of gallic acid equivalents per g of dry weight of samples (mg GAE/g DW). The results were an average of three independent measurements of the samples.

The total flavonoid content was determined according to the method of Kan, Nie, Hu, Wang, et al. (2016). Briefly, 0.5 mL of rutin standard solution or extract and 0.1 mL of sodium nitrite, \( \text{NaNO}_2 \) (5g/100mL) and 4 mL of distilled water were mixed together and left to react for 6 min. 3 mL of 1 mol \( \text{NaOH} \) was injected into the mixture to terminate the reaction. After 15 min for the colour reaction, the absorbance of the extract was recorded at 510 nm. The standard curve was linear at a concentration ranging from 0.1 to 0.5 mg/mL of rutin equivalents. The flavonoid content was expressed as mg of rutin equivalents per g of dry weight of novel rice noodle samples (mg RE/g DW). The results were an average of three independent measurements of the samples.

3.5.5.6 Antioxidant activities

3.5.5.6.1 DPPH radical scavenging activities

The ability of the novel rice noodle samples to scavenge DPPH radical were determined by the method of J. Wang et al. (2015) with some slight modifications. Briefly, the 0.1 mmol/L DPPH in 95%
ethanol was prepared on the same day before UV measurements. 100 μL of the Trolox standard solution or sample extract of proper concentrations (2-fold dilute with ethanol was applied to some sample) was mixed with 100 μL of freshly prepared DPPH in a 96-well plate. 100 μL of sample extract was combined with 100 μL of 95% ethanol for preparing the sample blank. DPPH standard was done by mixing 100 μL of DPPH and 100 μL of distilled water. All the mixtures were shaken vigorously and left to react for 30 min in darkness, and the absorbance was then recorded at 517 nm against a sample blank using a Varioskan Flash microplate reader (Thermo Fisher Scientific, Waltham, MA, USA). The DPPH scavenging activity was calculated by:

\[
I\% = \left[ 1 - \frac{(A_2 - A_1)}{A_0} \right] \times 100
\]

\(A_0\) was the absorbance of DPPH reagent at 517 nm (DPPH standard); \(A_1\) was the sample absorbance without DPPH (Blank); \(A_2\) was the sample absorbance. The standard curve was linear at concentration from 0.0025 to 0.01 mg/mL of the Trolox standard. The DPPH scavenging ability was expressed as mmol of Trolox per g dry mass of samples (mmol TE/g DW). Each sample was tested in triplicate and the average is reported.

3.5.5.6.2 Ferric reducing antioxidant power (FRAP) assay

The antioxidant activity was quantified by the FRAP assay according to the method of Chen et al. (2014) with slight modifications. The FRAP reagent included 300 mM acetate buffer (3.1 g sodium acetate with 16 ml glacial acetic acid, pH 3.6), 10 mM TPTZ (2,4,6-tripyridyl-s-triazine) solution within 40 mM HCl; and 20 mM FeCl₃ were combined in a ratio of 10:1:1; v/v/v. 100 μL of Fe (II) standard solution or extract was mixed with 1.8 mL of FRAP reagent in a 96-well microplate. The plate was incubated at 37 °C for 10 min in darkness before the absorbance was recorded at 593 nm. The standard curve was linear at concentration at 0.0625, 0.125, 0.25, 0.5 and 1.0 mmol/L of FeSO₄·7H₂O. The ferric reducing antioxidant activity was stated as μmol of Fe (II) equivalent per g of the dry mass of samples (μM Fe (II) /g DW). The results were an average of three independent measurements of the samples.
3.3.6 Sensory evaluation

The sensory evaluation was conducted at Nanchang University, China. 80 consumers were selected with previous consuming rice noodle experiences in the age group of 22–45 years (53 female and 37 male) were selected for sensory evaluation at Nanchang University by filling out a designed questionnaire. Six novel rice noodle samples were selected based on the results of textural properties and nutrition content, which were: RN2, C30: R70, C50: R50, L30(F): R70, L30: R70, and L30(P):R70. Sensory analysis was conducted for both dried and cooked rice noodle products. The rice noodles were considered as cooked according to put them into boiling water for cooked time measured in Section 3.3.2. All the noodles were served warm by put hot water at 80˚C in each sample cups. All rice noodles samples were randomized labeled with 3-digit codes. The uncooked (dry) samples were evaluated for liking of surface appearance. Participants got one stripe (~15 g) of each cooked rice noodle samples and were evaluated for appearance and general sensory profile, including hardness, chewiness, smoothness, springiness, taste and overall acceptability (OA). The samples were evaluated based on a nine-point hedonic scale (1 = extremely dislike it; 2 = Dislike it very much; 3 = Dislike it moderately; 4 = Dislike it slightly; 5 = Neither like nor dislike; 6 = Like it slightly; 7 = Like it moderately; 8 = Like it very much; 9 = like it extremely) for dried surface, cooked noodle surface, taste, colour and OA. The intensity of smoothness, chewiness, hardness and springiness were measured based on a nine-point category scale ranging from low (1) to high (9). A separate question was asked about willingness to purchase (WTP) of the product based on a five-point category scale to evaluate their chance of buying the product (1 = never, 2 = seldom, 3 = sometimes, 4 = normally and 5 = always). Some demographic questions were included to collect general information of the evaluators and investigate some trends with the results, such as age, gender, education level, and how often they consume rice noodle.

3.3.7 In vitro starch digestibility and predicted GI

All rice noodles were prepared in the lab on the same day of the experiment. The cooked rice noodles were ground through a 4.5 mm grinder to mimic the oral phase of digestion. Moisture content
was investigated separately using a Mettler Toledo moisture analyzer (HB43-S, halogen) on the same day with the average of 3 separate independent measurements. The calculation of the amount of sample used for *in vitro* digestion was using the following equation:

\[
\text{Fresh sample used (wet weight base, wwb) = 200 mg sample (dry weight base, dwb) \times (100 / starch \%) \times 100/(100 - MC\%).}
\]

Starch digestibility of both chickpea and lentil flour formulated rice noodles were determined using the GI Analyser (NutriScan Artificial Gut, GI/RS20, Next Instruments, NSW, Australia), which was comparable to standard Englyst procedures (Englyst et al., 1992). The cooked rice noodles containing 200 mg (±5 mg) (dwb) of available starch were added into a 120 mL plastic sample container. 4 mL of pepsin (Sigma P7125)/guar gum solution were added for each sample tubes. Then the samples were incubated on the GI analyzer heating and stirring (~200 stroke/min) for 30 min at 37 °C. Afterward, 44 mL of pre-warmed sodium acetate buffer (pH 5.2, 40°C) were added to all samples and allowed to equilibrate at 37 °C for 5 min. The samples entered the pancreatic and intestinal phases by the addition of enzyme mixture of pancreatin (Sigma P7545), AMG, and invertase (Sigma, I4504). 500 µL aliquot was taken out from the sample cups for 0 min glucose reading and applied as blank. The final sample mixtures were incubated for 2 h, during which the glucose concentration in the samples were measured with a glucose analyzer (Analox Instruments, GL6, Stourbridge, UK) at specific time periods (20, 60, and 120 min). Digested starch per 100 g DM was calculated as the following equation:

\[
\% \text{ digestible starch} = G \times \frac{\text{total volume (ml)}}{0.5 \text{ ml}} \times \frac{100}{W} \times 0.9
\]

Where G= glucose concentration (mg/dL); total volume = changes according to a number of aliquots removed during each time point; W= dwb of the sample in mg; 0.9= factor to convert free glucose into anhydro-glucose, as it occurred in starch (162/180). The RDS = the % digestible starch at first 20 min; the SDS = % digestible starch at 120 min - the % of digestible starch at 20 min; the RS = TS - (RDS + SDS). All the food samples were run in duplicate for two consecutive days to make sure the results were reproducible and constant.
The kinetics of *in vitro* starch digestion was accorded to a nonlinear, first order kinetic model accomplished by Goñi et al. (1997):

\[ C = C_\infty(1 - e^{-kt}) \]

Where \( C \) represented the starch hydrolyzed at \( t \) (min) time, \( C_\infty \) was the equilibrium constant, and \( k \) represented the kinetic constant and \( t \) (min) was the time chosen. The parameters, \( C_\infty \) and \( k \), were estimated for each treatment based on the data obtained from the *in vitro* starch digestion using SigmaPlot 13.0 (Systat Software, San Jose, CA).

The area under the hydrolysis curve (AUC) was calculated by the following equation, which was the integral of the Goñi et al. (1997):

\[ \text{AUC} = C_\infty(t_f - t_0) - \left( \frac{C_\infty}{k} \right) \left[ 1 - \exp\left\{ -k(t_f - t_0) \right\} \right] \]

Where \( C_\infty \) was the equilibrium percentage of starch hydrolyzed after 120 min, \( t_f \) was the final time (120 min), \( t_0 \) was the initial time (0 min), and \( k \) was the kinetic constant. The hydrolysis index (HI) was determined from the ratio of the AUC of each treatment by the AUC obtained from the reference food (white bread). The predicted GI was calculated using two equations described by Goñi et al. (1997): \( pGI = 8.198 + 0.862*HI \) and Granfeldt, Bjorck, Drews, and Tovar (1992): \( pGI = 39.71 + 0.549*HI \).

### 3.4 Statistical analysis

The results for the majority of the test analyzed (except Table 13) were expressed as means ± standard deviation (SD). The statistical analysis was performed using One-way analysis of variance (ANOVA) under Duncan’s multiple-range test and Pearson’s correlation coefficient was calculated using the IBM SPSS Statistics (version 19.0, Chicago, USA). A value of \( p < 0.05 \) was regard as statistical significance.
Chapter 4. Results and discussion

4.1 Selection of raw rice material for rice noodles production

There was a significant difference between the amylose contents of the 3 rice varieties (p < 0.05), which ranged from 21.99% to 28.73% of the total starch content. Among these rice varieties, Japonica (R3) had the highest amylose content, while late harvested Indica (R1) had the lowest (Table 4). It has been reported that indica rice was the most suitable variety to produce rice noodles with desirable cooking properties and textures (Han et al., 2011; S. Zhao et al., 2002). However, rice starch with 24% to 26% amylose content of the total starch constituents produced the best quality of the rice noodle (H. Li et al., 2005; Sun et al., 2004). Therefore, the amylose content of Japonica exceeded desirable condition, and late harvested Indica rice contained slightly lower amylose content as required. Early harvested Indica rice was within the desirable range (24 to 26% of amylose of rice starch) for making good quality rice noodle. But the closer to 26% amylose content, the higher the quality of the rice noodles, since rice starch with 26% amylose exhibited better gelatinization and retrogradation ability of the produced rice noodles than the starches containing closer to 24% of amylose (Sun et al., 2004). Thus, a combination of 3 rice varieties with 1:1:1 ratio had desired amylose content closest to 26%.

Pasting properties of the 3 rice varieties have been investigated as well and showed similar pasting patterns (Table 5). The pasting properties can be used to evaluate the quality of rice noodles. The pasting temperature of all the RF samples ranged from 76.8 (Japonica) to 78.4°C (Late harvested Indica), which is an indication of minimum temperature required to cook the starch. These findings were in agreement with results provided by N. Wang et al. (2014) that high amylose content resulted with lower PT (Table 5). Highest PV of 3376 cP was detected from late harvested indica rice, which might be related to its higher swelling power (water-binding capacity of starch granules) compared with other RF samples tested, since it has the lowest amylose or even longer chain length amylopectin in comparison with other RF samples (Klein et al., 2013). The PV of RF samples ranged in the following order: late harvested Indica (R1) > early harvested Indica (R2) > RM > Japonica (R3). High amylose and fine structure amylopectin may
suggest the more intact starch structure with higher hot paste stability, which results with lower BDV (Pinto et al., 2012). The FV of all 3 rice varieties and RM had relatively small BDV caused by high amylose content ranging from 492 cP to 2180 cP, with lowest BDV from R3 and following with RM, R2 and R1.

Furthermore, during the cooking cycle, high FV was related with high amylose content, as it leads to high starch retrogradation and gel hardness (Klein et al., 2013). The FV of all 3 rice varieties and RM placed from high to low in the following order: R3 > RM > R2 > R1. SBV could be influenced by size or the changes of starch granules, amylose leaching (solubility) and amylose content (Klein et al., 2013). Since high amylose material has a higher capability of rearrangement to an ordered phase during retrogradation, the highest amylose content of the R3 had the highest SBV of 1888 cP, followed with RM, R2 and R1. Furthermore, high SBV indicates higher gel hardness and cold paste stability. R3 had exceeded the desired rice noodle condition and the resulting product was out of the acceptable texture range (Klein et al., 2013; F. Wu et al., 2015).

With the overall comparison of all three rice varieties, the blend of three rice varieties with 1:1:1 ratio (RM) exhibited the most suitable physiochemical properties to producing the rice noodle that was similar to the commercial product. Other ratios have also been considered to produce rice noodles with the rice noodle extruder with designed method mentioned in Section 3.2.5, however the combination of the three varieties showed overall the best rice noodle quality.

Table 4. Amylose content of rice starches within rice flour samples.

<table>
<thead>
<tr>
<th>Samples</th>
<th>% of total starch</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>21.99±0.19a</td>
</tr>
<tr>
<td>R2</td>
<td>24.73±0.50b</td>
</tr>
<tr>
<td>R3</td>
<td>28.73±0.04d</td>
</tr>
<tr>
<td>RM</td>
<td>25.85±0.03c</td>
</tr>
</tbody>
</table>

a-d Difference superscripts within the same column are significantly different by Duncan's multiple range test (p < 0.05). All values are mean ± SD of three replicates.
Table 5. Pasting properties of rice flour samples.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Peak Visc (cP)</th>
<th>Breakdown (cP)</th>
<th>Final Visc (cP)</th>
<th>Setback (cP)</th>
<th>Pasting Temp (˚C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>3376±21d</td>
<td>2180±5d</td>
<td>2270±21a</td>
<td>1079±10a</td>
<td>78.35±0.3c</td>
</tr>
<tr>
<td>R2</td>
<td>3098±16c</td>
<td>1871±9c</td>
<td>2396±6b</td>
<td>1162±6b</td>
<td>77.85±0.1bc</td>
</tr>
<tr>
<td>R3</td>
<td>2438±8a</td>
<td>492±5a</td>
<td>3807±7d</td>
<td>1888±7d</td>
<td>76.80±0.2a</td>
</tr>
<tr>
<td>RM</td>
<td>2890±11b</td>
<td>1573±29b</td>
<td>2630±21c</td>
<td>1404±19c</td>
<td>77.30±0.2b</td>
</tr>
</tbody>
</table>

a-d Difference superscripts within the same column are significantly different by Duncan's multiple range test (p < 0.05). All values are mean ± SD of three replicates. Abbreviation: PV peak viscosity, TV through viscosity, BDV breakdown viscosity, FV final viscosity, SBV setback viscosity, PT pasting temperature.

4.2 Characterization of raw pulse fortified rice mixtures

4.2.1 Amylose content

The amylose content acts as an important component influencing the rice noodle quality (F. Wu et al., 2015). The percentage of amylose content for flour starches (pulse, rice and their mixtures) and amylose content of total constituents of the flour samples are presented in Table 6. With increased pulse flour substitutions, the amylose content of the novel rice noodle flour blends was decreased. This decrease could be attributed to both chickpea and lentil starches had approximately 23% amylose, which was lower than rice starch with approximately 26% amylose. However, the main reason of the decreased amylose content was attributed to the fact that both pulse flours contained lower total starch content (~50 g/100 g DM) as compared with RM, which contained 86 g/100 g DM starch content, in agreement with results of Chung, Liu, Hoover, et al. (2008) (Table 12). Higher amylose content would result in stronger gels for rice noodle and lower cooking loss (Lii & Chang, 1981; N. Wang et al., 2014; F. Wu et al., 2015). Thus, the quality of the novel rice noodle might decrease with increased pulse flour substitutions. Moreover, the chickpea flour had 11.66% amylose content, which was slightly lower than lentil flour that contained 12.10 % amylose content of the total composition. Thus, lentil flour fortification might have a better-quality rice noodle than chickpea flour incorporated rice noodles, as lentil flour substitution showed a slightly higher amylose content than chickpea flour, except 50% substitution. At 50%, CF-RF mixtures had 17.80 % amylose content, which was 1.44% greater than 50% lentil flour substitution, this
might relate to the poor noodle quality with an elevation of lentil flour substitution. Notably, lentil (F) showed highest (13.14%) and lentil (N) had the lowest (11.61%) amylose content of all the lentil flour samples. This observation indicated most of the amylose content of the lentil flour starch was contained within the cotyledon of the lentil flour, as most of the lentil (N) contained the hull of lentil flour. As a result, the L30(F):R70 had the highest amylose content (20.20%) among all the lentil flour substitutions and should be producing better quality rice noodle and lower cooking loss among all lentil flour incorporated novel rice noodles.

Table 6. Amylose content of starches and flour samples mixed with different pulse flour.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Amylose % of total starch</th>
<th>Amylose % of total rice constituents</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM</td>
<td>25.85±0.03f</td>
<td>20.50±0.02j</td>
</tr>
<tr>
<td>CF</td>
<td>22.99±0.71b</td>
<td>11.66±0.36a</td>
</tr>
<tr>
<td>LF</td>
<td>22.82±0.05b</td>
<td>12.10±0.03b</td>
</tr>
<tr>
<td>lentil (F)</td>
<td>24.64±0.32d</td>
<td>13.14±0.17c</td>
</tr>
<tr>
<td>lentil (N)</td>
<td>21.77±0.40a</td>
<td>11.61±0.21a</td>
</tr>
<tr>
<td>L15:R85</td>
<td>25.39±0.02ef</td>
<td>19.92±0.02h</td>
</tr>
<tr>
<td>L30:R70</td>
<td>24.94±0.02de</td>
<td>18.67±0.01f</td>
</tr>
<tr>
<td>L30(F):R70</td>
<td>25.49±0.11f</td>
<td>20.20±0.09i</td>
</tr>
<tr>
<td>L50:R50</td>
<td>23.92±0.10c</td>
<td>16.36±0.07d</td>
</tr>
<tr>
<td>C15:R85</td>
<td>25.42±0.12ef</td>
<td>19.34±0.10g</td>
</tr>
<tr>
<td>C30:R70</td>
<td>24.93±0.03de</td>
<td>18.45±0.02f</td>
</tr>
<tr>
<td>C50:50</td>
<td>24.85±0.44d</td>
<td>17.80±0.3e</td>
</tr>
</tbody>
</table>

a-j Difference superscripts within the same column are significantly different by Duncan's multiple range test (p < 0.05). All values are mean ± SD of three replicates

4.2.2 Thermal Properties

The endothermic transitions of chickpea, lentil and rice flour with various combinations are shown in Table 7. Rice, lentil and chickpea flour with various combinations showed a single transition which reflected gelatinization, except the 100% chickpea flour exhibited two relatively small individual endothermic transitions caused by starch gelatinization and disruption of the amylose-lipid complex. This effect might be caused by the fact chickpea flour contained a higher amount of lipid than rice and lentil.
flour (Table 12). Furthermore, it has been noticed at 30% and 50% chickpea substitution levels, DSC displayed two gelatinization peaks: one for chickpea starch gelatinization (1st peak) and the other one for rice starch (2nd peak). This phenomenon indicates each component (rice and chickpea) gelatinized independently. Several studies suggested that the development of two peaks in the two-component system correlated with starch concentration, the type of starch included and the ratio of each starch incorporated into the mixture (F. Zhu & Corke, 2011).

Onset temperature decreased and peak temperature was not significantly influenced with increased lentil flour substituted into RM (Table 7). This phenomenon indicates that with the lentil flour substitution at the initial stage the starch granule swells slower. ΔH decreased for lentil flour substitutions. However, the changes in amylose content and resistant starch content could alter the crystallinity degree and lead to a decrease in ΔH (Srikaeo & Sangkhiaw, 2014). There was no significant difference between the three different kinds of lentil flour substitutions, except ΔH, which was decreased for L30(P):R70 with the psyllium addition, suggesting less energy was needed to cook this particular starch sample.

ΔH decreased with increasing chickpea flour substituted into RM. The two gelatinization peaks might account for this decline. The lower ΔH suggested that they were easier to cook. Hence, substitution of chickpea flour and 50% or even L30(P):R70 Lentil flour substitution into RM might improve the cooking quality of rice noodles, especially reduce the cooking time. The difference in chickpea and RM mixtures showed increased onset, peak and conclusion temperature with increased levels of chickpea flour, indicating the starch granules were a bit difficult to swell and gelatinize. Many studies suggested that there was a positive linear correlation between gelatinization temperature and dietary fiber or resistant starch content, which might explain the increase of thermal properties, e.g. gelatinization temperatures of chickpea flour substitution into RM (Morita, Ito, Brown, Ando, & Kiriyama, 2007; Srikaeo & Sangkhiaw, 2014).

Altogether, the degree of gelatinization (DG) ranged from 85.02 to 99.54%, as shown in Table 7. ΔH was negatively correlated with degree of gelatinization (r = -0.971, p < 0.01). The rice noodle had the lowest degree of gelatinization, which might contribute to its higher ΔH, excessive starch content that
required higher energy to gelatinize the starch and an insufficient temperature provided during the extrusion process. Therefore, this might negatively affect the cooking quality of the rice noodle, such as increasing the cooking time (Sozer, Dalgic, & Kaya, 2007). With increased pulse flour substitutions, the degree of gelatinization increased. Lentil flour fortifications on the whole presented lower degree of gelatinization (87.54 to 89.28) than chickpea flour substituted rice noodles (89.90 to 99.54). These observations could be explained by lower starch content and gelatinization entropy of chickpea than lentil flour substitutions (Table 7 & 12). Meanwhile, L30(P):R70 exhibited highest degree of gelatinization among all the lentil flour substituted blends. This finding could be caused by the addition of psyllium, which might change the morphology of the starch granules during extrusion/cooking and cause this particular blend to be easier gelatinized after extrusion. In conclusion, based on the study of the thermal properties of the pulse substituted rice noodle mixtures, the chickpea flour substituted rice noodles should obtain better cooking quality than lentil flour incorporated rice noodles.

Table 7. Thermal Properties of samples with different chickpea/lentil flour substitution.

<table>
<thead>
<tr>
<th>Samples</th>
<th>$T_o$ (°C)</th>
<th>$T_p$ (°C)</th>
<th>$T_c$ (°C)</th>
<th>$\Delta H$ (J/g)</th>
<th>DG (%) $^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LF</td>
<td>70.02±0.05b</td>
<td>79.69±0.11b</td>
<td>104.92±0.29g</td>
<td>6.12±0.04d</td>
<td>ND</td>
</tr>
<tr>
<td>CF</td>
<td>65.80±0.00a</td>
<td>73.55±0.02a</td>
<td>93.91±0.37a</td>
<td>5.85±0.19c</td>
<td>ND</td>
</tr>
<tr>
<td>RM</td>
<td>74.76±0.13d</td>
<td>81.82±0.19c</td>
<td>96.73±0.36b</td>
<td>8.79±0.06g</td>
<td>85.02±0.69a</td>
</tr>
<tr>
<td>L15:R85</td>
<td>75.33±0.31e</td>
<td>83.93±0.16d</td>
<td>96.67±0.37bcd</td>
<td>7.78±0.09f</td>
<td>87.54±0.07c</td>
</tr>
<tr>
<td>L30(F):R70</td>
<td>73.19±0.12c</td>
<td>84.70±0.10e</td>
<td>97.52±0.32de</td>
<td>7.32±0.08e</td>
<td>87.32±0.07c</td>
</tr>
<tr>
<td>L30:R70</td>
<td>72.89±0.11c</td>
<td>84.63±0.06e</td>
<td>97.49±0.42de</td>
<td>7.12±0.08e</td>
<td>87.22±0.05c</td>
</tr>
<tr>
<td>L30(P):R70</td>
<td>72.49±0.11c</td>
<td>84.64±0.07e</td>
<td>98.04±0.40e</td>
<td>6.95±0.02de</td>
<td>89.28±0.10d</td>
</tr>
<tr>
<td>L50:R50</td>
<td>70.20±0.17b</td>
<td>84.66±0.18e</td>
<td>99.02±0.45f</td>
<td>6.90±0.20de</td>
<td>87.09±0.27c</td>
</tr>
<tr>
<td>C15:R85</td>
<td>76.22±0.16f</td>
<td>83.68±0.24d</td>
<td>96.37±0.10bc</td>
<td>5.73±0.43c</td>
<td>89.90±0.02d</td>
</tr>
<tr>
<td>C30:R70</td>
<td>77.12±0.30g</td>
<td>84.95±0.26e</td>
<td>97.20±0.38cde</td>
<td>4.42±0.02b</td>
<td>94.90±0.03e</td>
</tr>
<tr>
<td>C50:R50</td>
<td>78.80±0.19h</td>
<td>86.18±0.26f</td>
<td>97.92±0.40e</td>
<td>2.66±0.06a</td>
<td>99.54±0.01f</td>
</tr>
</tbody>
</table>

a-h Difference superscripts within the same column are significantly different by Duncan’s multiple range test (p < 0.05). All values are mean ± SD of three replicates. Abbreviation: $T_o$ = Onset Temperature, $T_p$ = Peak Temperature, $T_c$ = Conclusion Temperature, $\Delta H$ = gelatinization entropy, ND = not determined

$^1$DG = degree of gelatinization after extrusion of the rice noodles
4.2.3 Pasting Properties

Lentil and chickpea flour combined with RM displayed similar pasting patterns (Figure 3). However, chickpea flour behaved in agreement with the results of Chung, Liu, Hoover, et al. (2008), that chickpea flour increased in viscosity during the holding period (95°C), while lentil flour behaved differently. The increase in viscosity was caused by starch granules swelling. The pasting temperature of all the flour samples ranged from 74.30 (LF) to 84.8°C (RM) (Table 8). Chickpea and lentil flour exhibited the highest PT. PT was slightly raised with increased pulse concentrations in comparison with RM, even though with significantly decreased amylose content (Table 5). This observation could be attributed to pulse flours containing higher protein content than RM (Table 12), which could induce increased protein-starch interaction, hence, resulted in reduced granule swelling and higher PT than RM (Chung, Liu, Hoover, et al., 2008). Another possible reason to cause the increase of PT was that RM usually has much smaller sized starch granules (2-7μm) than both chickpea (20-35μm) and lentil flour (10-30μm) (N. Singh et al., 2008; N. Wang & Daun, 2004). Smaller starch granular size could contribute to reducing PT because they allowed rapid hydration with greater surface area exposed. Thus, rice starch granules swell faster and lead to gelatinization of starch early at a lower temperature in comparison to pulse starch granules with bigger granular size (Ahmed et al., 2016). As a result, with increased pulse substitution, the granular size of the starches increased, which led to higher PT of the blends than RM. Furthermore, lentil flour substituted blends showed no significant difference (p <0.05) with various substitution levels. But chickpea flour substituted rice noodle blends had a higher PT than lentil flour substituted blends because chickpea flour has a larger starch granular size than lentil flour.

Setback Viscosity (SBV), Final Viscosity (FV), Breakdown Viscosity (BDV) and Peak Viscosity (PV) were decreased with increased pulse substitutions (Table 8). Novel rice noodles showed significant difference (p < 0.05) in these pasting properties with various substitution levels (Table 8). This observation could be caused by many reasons, including chickpea and lentil flour had lower starch content and increased amount of lipid, protein and fibers. Since same pasting patterns have been observed from other
pulse flours such as mung bean and broad bean flours in comparison to RF (Q. Liu et al., 2006). Specifically, the PV was attributed to adequate numbers of granules becoming swollen, and it is an indication of the water-binding capacity of the starch. The PV ranged from 678 (CF) to 2890 cP (RM). The breakdown viscosity (BDV) indicates how easy the swollen granules can be disintegrated and ranged from 17 (CF) to 1573 cP (RM) (Table 8). The lower PT, PV and BDV in the pulse substitution mixtures could be attributed to their lowered amylose content and decreased swelling power (caused by increased protein content) compared to RM. The lentil flour replacements, in general, showed higher PV and BDV than chickpea flour substitutions, except PV of 50% chickpea flour substitution had slightly higher viscosity than 50% lentil flour substitution, which might be caused by 50% chickpea substitution having slightly greater amylose content than 50% lentil flour substitution and/or the starch granules containing more short chain amylopectin at this particular percentage of mixture for chickpea flour substitution. Altogether, the lower gelatinization properties of chickpea flour substitutions than lentil flour was attributed to chickpea flour usually having less swelling power than lentil flour at above 60°C, because chickpeas have a smaller amount of hydrophilic carbohydrates and water-soluble proteins than lentils. Besides, lentil flour has been known to have high water binding capacity among all other pulse flours (Chung, Liu, Hoover, et al., 2008).

The FV is a measure of the ability of starch to form a gel and SBV indicates the retrogradation tendency upon cooling, which is mainly due to a reassociation of leached amylose. The FV and SEB of all flour samples ranged from 798 to 2630 cP and 143 to 1404 cP, respectively. Lentil flour substitutions exhibited better retrogradation tendency than chickpea flour replacement indicating their ability to form a better gel. N. Wang et al. (2014) suggested that there is a positive correlation between SBV and amylose content. The higher SBV of lentil flour substitution than chickpea flour substitution might be because of they have higher granule rigidity and higher amylose leaching (N. Wang et al., 2014). Besides, L30(P):R70 had lower BDV, higher PV, FV, SBV and PT than just 30% lentil flour substitution. This phenomenon might be due to psyllium having great ability to absorb and retain water, which will improve the final gelling quality of starch granules and in turn improve the quality of novel rice noodle (Cappa et al.,
Also, the L30(F):R70 had reduced BDV, PT and higher PV, FV and SBV than regular L30:R70, which could be caused by the lentil (F) having a higher amylose content (1.03 g/100 g DM) than regular lentil flour, which positively improved the gelatinization and retrogradation ability of the lentil flour.

**Table 8.** The pasting properties of samples with different chickpea/lentil flour substitutions.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Peak Visc (cP)</th>
<th>Breakdown (cP)</th>
<th>Final Visc (cP)</th>
<th>Setback (cP)</th>
<th>Pasting Temp (˚C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM</td>
<td>2890±11k</td>
<td>1573±29k</td>
<td>2630±21k</td>
<td>1404±19j</td>
<td>77.3±0.2a</td>
</tr>
<tr>
<td>LF</td>
<td>735±3b</td>
<td>23±1b</td>
<td>1177±0b</td>
<td>459±3b</td>
<td>79.7±0.2c</td>
</tr>
<tr>
<td>CF</td>
<td>678±22a</td>
<td>17±2a</td>
<td>798±24a</td>
<td>143±1a</td>
<td>84.8±0.1f</td>
</tr>
<tr>
<td>C15:R85</td>
<td>1886±14i</td>
<td>673±10i</td>
<td>2392±4f</td>
<td>1179±0f</td>
<td>79.0±0.0bc</td>
</tr>
<tr>
<td>C30:R70</td>
<td>1366±19e</td>
<td>241±8f</td>
<td>2206±30e</td>
<td>1081±19e</td>
<td>80.3±0.01d</td>
</tr>
<tr>
<td>C50:R50</td>
<td>1088±3d</td>
<td>108±1c</td>
<td>1793±8c</td>
<td>813±9c</td>
<td>81.4±0.3e</td>
</tr>
<tr>
<td>L15:R85</td>
<td>1987±15j</td>
<td>751±13j</td>
<td>2622±10j</td>
<td>1393±7i</td>
<td>78.1±0.0b</td>
</tr>
<tr>
<td>L30(F):R70</td>
<td>1548±6g</td>
<td>221±5e</td>
<td>2557±29i</td>
<td>1330±17g</td>
<td>78.5±0.7b</td>
</tr>
<tr>
<td>L30:R70</td>
<td>1394±25f</td>
<td>287±11h</td>
<td>2482±1g</td>
<td>1325±37g</td>
<td>78.3±0.2b</td>
</tr>
<tr>
<td>L30(P):R70</td>
<td>1587±18h</td>
<td>258±2g</td>
<td>2566±6h</td>
<td>1379±9h</td>
<td>78.6±0.3b</td>
</tr>
<tr>
<td>L50:R50</td>
<td>1046±13c</td>
<td>131±9d</td>
<td>1990±16d</td>
<td>1075±12d</td>
<td>79.0±0.2bc</td>
</tr>
</tbody>
</table>

a-k Difference superscripts within the same column are significantly different by Duncan’s multiple range test (p < 0.05). All values are mean ± SD of three replicates. Abbreviation: PV = peak viscosity, BDV = breakdown viscosity, FV = final viscosity, SBV = setback viscosity, PT = pasting temperature.

**Figure 3.** Pasting properties of novel rice noodles made with different pulses substitutions.
4.3 General quality of extruded rice noodles

4.3.1 Cooking properties

Cooking properties are another set of important parameters to determine the quality of rice noodles. The cooking properties for rice noodles usually include cooking time (time required to cook the rice noodles), cooked weight (water adopted during cooking) and cooking loss (weight of leached residues in cooking water). Cooking time for novel rice noodles with different pulse flour substitutions ranged from 12.45 (RN2) to 6.37 (L50:R50) min (Table 9). During the boiling period, the amorphous region becomes hydrated and causes the amylose networks to swell and subsequently become degraded, leading to increase of amylose leaching in water with increased cooking time (N. Wang et al., 2014). RN1 exhibited the longest cooking time of 19.82 min, followed by RN2 of 12.45 min. The difference in time might be caused by various processing method or different rice materials used. With increased percentage of pulse incorporation, the cooking time decreased. The cooking time ranged from 6.37 to 12.33 min for lentil flour fortified rice noodles and 8.70 to 11.37 min for chickpea flour fortified rice noodles. This decrease might be due to that pulse starch usually took a shorter time to cook. For example, cooking time for lentil and pea starch noodles were from 5.25 to 6.5 min (N. Wang et al., 2014). Cooking time was also positively correlated with amylose content ($r = 0.903$, $p < 0.01$) and PV ($r = 0.706$, $p < 0.05$) as observed in this study, which is in accordance with the finding of N. Wang et al. (2014). The lower PV and amylose content in novel rice noodles could result in increased swelling power and less time to hydrate compared to rice noodles. In addition, the cooking time was significantly reduced with the addition of 0.25% psyllium (8.43 min) (L30(P):R70) as compared with 30% lentil substitutions without psyllium. This observation could be attributed to the addition of 0.25% psyllium increased the water absorption of the 30% lentil flour substituted rice noodle, since psyllium have been known to has a greater ability to absorb and retain water (Cappa et al., 2013). Thus, more water (200 mL) was required for the processing of L30(P):R70.

Cooking loss of novel rice noodles ranged from 0.05 to 0.15% (Table 9). Cooking loss was caused
by loosely-bound gelatinized starch leaching to the boiling water and highly related to the strength of starch retrogradation (F. Wu et al., 2015). The cooking loss was increased significantly (p < 0.05) with increased pulse flour substitutions, except at 50% chickpea flour substitutions (0.11%), which had a slightly lower cooking loss than 30% chickpea flour substitutions (0.12%). Amylose content also negatively correlated with the cooking loss (r = -0.793, p < 0.05) indicating higher amylose content could form a stronger gel, which reduced the cooking loss (Lii & Chang, 1981). This result could explain the L30(F):R70 exhibited the lowest cooking loss of 0.11% among all the 30% lentil flour substitutions, followed by L30(P):R70 and then L30:R70. The lower cooking loss of L30(P):R70 could be due to the presence of psyllium, which increased the gelling ability of the fortified rice noodle. Source of starch influences the cooking loss of rice noodle samples; lentil substituted rice noodles exhibited higher cooking loss than chickpea flour substituted rice noodles, even with a slightly higher amylose content. Chung, Liu, Hoover, et al. (2008) reported that chickpea flour had the lowest amylose leaching compared to lentil and pea flours, which could be one of the reasons attributing to the variation in the cooking loss. Moreover, it was observed in this study that PV was negatively correlated with cooking loss (r = -0.793, p < 0.05) and was consistent with the observation from the study of N. Wang et al. (2014). During extrusion of the rice noodle, extensive degradation of both amylose and amylopectin (Colonna & Mercier, 1983) decreased the molecular weight of the starch and improved water solubility of the extruded rice noodles (N. Wang et al., 2014). Therefore, the material with higher PV would increase the friction of shear stress during extrusion, leading to a greater molecular degradation and cooking loss, which could explain the higher cooking loss from lentil than chickpea flour substitutions.

Rice noodles prepared from different pulse flours displayed a higher cooked weight as compared with RN2 (40.63%), but with much lower cooked weight in comparison to the commercial product (224.17%) (Table 9). The difference between RN2 and RN1 could be attributed to different processing condition (such as drying method) or raw ingredients used. Higher cooked weight was observed with chickpea than lentil flour substitutions, except L30(P):R70 had the highest cooked weight...
of 82.76% because the addition of psyllium increased the water absorbing and retaining ability of L30(P):R70 (Cappa et al., 2013). The cooked loss was negatively correlated with cooked weight \( r = -0.882, p < 0.01 \) and PV \( r = -0.742, p < 0.05 \) and was consistent with the observation from N. Wang et al. (2014). For extruded rice noodles, lower water absorption corresponded with high PV samples including RN2 and lentil flour substituted rice noodles, which would raise shear stress during the extrusion processing leading to structure changes and degradation of the starch, thus reducing cooked weight (N. Wang et al., 2014).

Table 9. Cooking properties of novel rice noodles made different pulse flour substitutions.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Cooking Time (Min)</th>
<th>Cooking Loss (%)</th>
<th>Cooked Weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RN1</td>
<td>19.82±0.45f</td>
<td>0.05±0.00a</td>
<td>224.17±3.09h</td>
</tr>
<tr>
<td>RN2</td>
<td>12.45±0.39e</td>
<td>0.09±0.01b</td>
<td>40.63±2.11a</td>
</tr>
<tr>
<td>C15:R85</td>
<td>11.37±0.44d</td>
<td>0.10±0.00c</td>
<td>44.11±1.95b</td>
</tr>
<tr>
<td>C30:R70</td>
<td>9.43±0.51c</td>
<td>0.12±0.01de</td>
<td>64.15±1.41c</td>
</tr>
<tr>
<td>C50:R50</td>
<td>8.70±0.18b</td>
<td>0.11±0.01c</td>
<td>79.47±4.27fg</td>
</tr>
<tr>
<td>L15:R85</td>
<td>12.33±0.29e</td>
<td>0.10±0.01c</td>
<td>39.76±2.77a</td>
</tr>
<tr>
<td>L30(F):R70</td>
<td>11.95±0.27de</td>
<td>0.11±0.01cd</td>
<td>51.62±2.33c</td>
</tr>
<tr>
<td>L30(R):R70</td>
<td>11.44±0.42d</td>
<td>0.14±0.00f</td>
<td>58.99±2.38d</td>
</tr>
<tr>
<td>L30(P):R70</td>
<td>8.43±0.08b</td>
<td>0.12±0.00e</td>
<td>82.76±3.23g</td>
</tr>
<tr>
<td>L50:R50</td>
<td>6.37±0.16a</td>
<td>0.15±0.01g</td>
<td>75.20±2.33f</td>
</tr>
</tbody>
</table>

a-h Difference superscripts within the same column are significantly different by Duncan's multiple range test \( p < 0.05 \). All values are mean ± SD of three replicates.

4.3.2 L*a*b* colour scale

Colour of rice noodles is one of the important aspects that needs to be considered. Consumers usually desire rice noodles with a brighter/whiter and clear colour (Lii & Chang, 1981). Novel rice noodles showed significant difference \( p < 0.05 \) in colour at various substitution levels (Table 10). As expected, all fortified rice noodles obtained high brightness \((L^*)\) ranging from 71.76 (L50: R50) to 97.77 (rice noodle). It had been observed that with increased pulse flour substitution the novel rice noodle exhibited decreased brightness, whereas lentil flour and RM combinations were less bright in colour than those from chickpea flour (Figure 4). B. Zhang et al. (2014) observed that bioactive components, such as
phenolic, carotenoids and flavonoids, are highly correlated with colour appearance, especially in highly pigmented pulses. Significant negative correlation of brightness with total phenolic content (TPC) \((r = -0.772, p < 0.01)\) and a weaker negative correlation with TFC \((r = -0.651, p < 0.05)\) was observed in present study. In addition, the results indicated that lightness was negatively correlated with DPPH radical scavenging activities \((r = -0.758, p < 0.01)\), and ferric reducing antioxidant power \((r = -0.644, p < 0.05)\), confirming the finding that darker colour legumes are positively correlated with TPC and antioxidant activities (Rocha-Guzmán et al., 2007; Xu & Chang, 2007).

Rice noodles prepared with different chickpea flour substitutions exhibited decreased greenness \((-a^*)\) ranging from -2.07 to -1.16 and increased yellowness \((b^*)\) ranging from 23.23 to 35.36 with increased incorporation levels compared with RN2 (Figure 4). This phenomenon corresponds to chickpea flour displaying the lowest greenness \((a^* = -0.63)\) and highest yellowness \((b^* = 37.33)\) in the present study. The higher yellowness of chickpea flour could be attributed to richer lipid content \((2.77 \text{ g/100g DM})\) than lentil flour \((0.93 \text{ g/100g DM})\) (Table 12). Rice noodles prepared with different lentil flour substitution displayed increased \(b^*\), but with lesser extent as compared with chickpea flour substitutions, ranging from 21.13 to 26.43. Greenness was improved to a greater extent with increasing lentil flour levels compared with chickpea flour substitutions, which ranged from -3.13 to -3.77 (Figure 4). This observation was due to lentil flour obtaining a higher greenness \((a^* = -4.90)\) than chickpea flour \((a^* = -0.63)\). \(a^*\) was negatively correlated with antioxidant activities, including both DPPH \((r = -0.762, p < 0.01)\) and weaker correlation was observed with FRAP \((r = -0.627, p < 0.05)\). This correlation indicated that lentil flour substitutions might have greater antioxidant activity than chickpea flour substituted rice noodle. No significant differences in colour parameters among the 3 rice noodle samples incorporated with 30% lentil flour, except for L30(F):R70 displayed a higher yellowness than the other two kinds. The higher yellowness of L30(F):R70 could be attributed to the raw material used. lentil (F) contained less lentil hulls and the seed inside was yellower compared to hulls.
Table 10. Colourimetric parameters of novel rice noodles made with different pulse flour substitutions.

<table>
<thead>
<tr>
<th>Samples</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>RN2</td>
<td>97.77±0.21i</td>
<td>-2.17±0.11cd</td>
<td>19.00±0.26a</td>
</tr>
<tr>
<td>CF</td>
<td>69.23±0.59b</td>
<td>-0.63±0.06f</td>
<td>37.33±0.11i</td>
</tr>
<tr>
<td>LF</td>
<td>63.56±0.31a</td>
<td>-4.90±0.53a</td>
<td>28.3±0.26f</td>
</tr>
<tr>
<td>C15:R85</td>
<td>96.17±0.49h</td>
<td>-2.07±0.15d</td>
<td>23.23±0.06c</td>
</tr>
<tr>
<td>C30:R70</td>
<td>93.63±0.06g</td>
<td>-1.93±0.23d</td>
<td>32.03±0.40g</td>
</tr>
<tr>
<td>C50:R50</td>
<td>91.67±0.45f</td>
<td>-1.16±0.21e</td>
<td>35.36±0.35h</td>
</tr>
<tr>
<td>L15:R85</td>
<td>81.43±0.45e</td>
<td>-3.13±0.26c</td>
<td>21.13±0.32b</td>
</tr>
<tr>
<td>L30(F):R70</td>
<td>74.00±0.37d</td>
<td>-3.10±0.20c</td>
<td>25.00±0.52e</td>
</tr>
<tr>
<td>L30:R70</td>
<td>73.33±0.06d</td>
<td>-3.20±0.21c</td>
<td>22.30±0.17c</td>
</tr>
<tr>
<td>L30(P):R70</td>
<td>73.57±0.49d</td>
<td>-3.40±0.06c</td>
<td>23.30±0.35c</td>
</tr>
<tr>
<td>L50:R50</td>
<td>71.76±0.21c</td>
<td>-3.77±0.29b</td>
<td>24.43±0.32d</td>
</tr>
</tbody>
</table>

a-h Difference superscripts within the same column are significantly different by Duncan’s multiple range test (p < 0.05). All values are mean ± SD of three replicates. Abbreviation: L* = lightness; a* = (+) red to (-) green; b* = (+) yellow to (-) blue.

Figure 4. Colourimetric parameters of novel rice noodles made with different pulse flour substitutions.

4.3.3 Texture properties

Texture properties are critical for consumer acceptance of the product (Hormdok & Noomhorm, 2007). Table 11 shows the texture properties of cooked novel rice noodles blended with different pulses.
flours. The texture properties were not significantly different (p < 0.05) between RN1 and RN2. In general, the hardness of the novel rice noodles ranged from 0.69 (C50:R50) to 1.45 N (L50:R50). Chicpea flour substitutions exhibited better texture properties than lentil flour substitutions, which mainly attributed to lentil flour has a coarser texture. For the chickpea flour substitutions, hardness was increased, and adhesiveness was reduced until 30% substitution compared with regular rice noodles, but decreased to 0.69 N for hardness and remained unchanged from 30% substitution (-0.09 N.s) for adhesiveness at 50% substitutions. Springiness represents the elasticity of the rice noodles, and was increased somewhat with increased chickpea flour substitution, but not significant, ranging from 0.60 to 0.71. Cohesiveness had increased at first (C15:R85) and then decreased to 0.13 for C50:R50 compared with rice noodle samples. Chewiness was influenced by hardness, cohesiveness, and springiness, as it was a product of these three parameters (Hormdok & Noomhorm, 2007). Thus, chewiness had increased at C15: R85 and was stable for C30:R70, then reduced to 0.07 which was same as the rice noodle samples (Sandhu & Kaur, 2010). Lentil substitution positively affects the hardness of the novel rice noodles, but L30(P):R70 displayed the closest hardness (0.81 N), cohesiveness (0.13) and chewiness (0.07) to the commercial rice noodle among all the lentil flour blends. The adhesiveness was negatively affected by the lentil flour substitutions until L30: R70 ranging from -0.11 to -0.15 N.s, then remain unchanged at -0.15 N.s for L50: R50. Another factor that might have contributed was the hull contained within the lentil flour, which increased the hardness and decreased the adhesiveness. Springiness was reduced with increasing lentil flour substitutions by 30% and raised to 0.66 for L50:R50. L30(F):R70 and L30(P):R70 exhibited significantly higher springiness of 0.71 and 0.69, respectively, compared with normal 30% lentil flour blended rice noodles. Moreover, lentil flour substitution negatively influenced cohesiveness. The L30(F):R70 obtained 0.05 higher cohesiveness than the normal 30% lentil flour blend, while there was no significant different (p < 0.05) between L30(F):R70 and L30(P):R70. Lastly, chewiness of lentil flour substitutions was influenced by all three parameters including hardness, springiness and cohesiveness as mentioned above. These results indicated C50:R50 altogether had the closest texture properties as compared with rice noodles, followed by
L30(P):R70. Therefore, these two types of rice noodles are suitable for sensory evaluation with consumers and further investigations among all the novel rice noodles samples.

Table 11. Texture properties of novel rice noodles with different pulse substitutions.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Hardness (N)</th>
<th>Adhesiveness (N.s)</th>
<th>Springiness</th>
<th>Cohesiveness</th>
<th>Chewiness</th>
</tr>
</thead>
<tbody>
<tr>
<td>RN1</td>
<td>0.74±0.03ab</td>
<td>-0.03±0.01f</td>
<td>0.65±0.05abc</td>
<td>0.14±0.01bc</td>
<td>0.07±0.00a</td>
</tr>
<tr>
<td>RN2</td>
<td>0.71±0.08ab</td>
<td>-0.03±0.01f</td>
<td>0.61±0.04abc</td>
<td>0.20±0.03d</td>
<td>0.08±0.01a</td>
</tr>
<tr>
<td>C15:R85</td>
<td>0.93±0.05cd</td>
<td>-0.08±0.01e</td>
<td>0.60±0.04abc</td>
<td>0.18±0.01cd</td>
<td>0.10±0.01bc</td>
</tr>
<tr>
<td>C30:R70</td>
<td>0.81±0.04abc</td>
<td>-0.09±0.04de</td>
<td>0.70±0.07bc</td>
<td>0.17±0.02bc</td>
<td>0.10±0.00bc</td>
</tr>
<tr>
<td>C50:R50</td>
<td>0.69±0.08a</td>
<td>-0.09±0.01de</td>
<td>0.71±0.11c</td>
<td>0.13±0.04bc</td>
<td>0.07±0.03a</td>
</tr>
<tr>
<td>L15:R85</td>
<td>0.85±0.21bc</td>
<td>-0.10±0.04bcd</td>
<td>0.54±0.16ab</td>
<td>0.20±0.05d</td>
<td>0.09±0.01b</td>
</tr>
<tr>
<td>L30(F):R70</td>
<td>1.01±0.04d</td>
<td>-0.11±0.02bc</td>
<td>0.72±0.08c</td>
<td>0.16±0.09bc</td>
<td>0.12±0.02c</td>
</tr>
<tr>
<td>L30:R70</td>
<td>1.45±0.13e</td>
<td>-0.15±0.01a</td>
<td>0.50±0.16a</td>
<td>0.11±0.04ab</td>
<td>0.08±0.03a</td>
</tr>
<tr>
<td>L30(P):R70</td>
<td>0.81±0.08abc</td>
<td>-0.13±0.01bc</td>
<td>0.69±0.03bc</td>
<td>0.13±0.05bc</td>
<td>0.07±0.01a</td>
</tr>
<tr>
<td>L50:R50</td>
<td>1.48±0.09e</td>
<td>-0.15±0.01a</td>
<td>0.66±0.12bc</td>
<td>0.10±0.01ab</td>
<td>0.10±0.01bc</td>
</tr>
</tbody>
</table>

a-e Difference superscripts within the same column are significantly different by Duncan’s multiple range test (p < 0.05). All values are mean ± SD, n = 5.

4.4 Chemical compositions of novel rice noodles

The chemical compositions of novel rice noodle blended with different percentages of pulse flours are shown in Table 12. Starch, dietary fiber and protein together composed more than 95% of the total rice noodle constituents. Other minor components of novel rice noodles are ash and fat. Ash content for novel rice noodle ranged from 0.29 (RN1) to 1.86 g/100 g DM (L50:R50), indicating with increased pulse incorporation the ash content (minerals) increased, because pulse provided a substantial amount of minerals including iron, potassium, magnesium, and zinc (Sandberg, 2002). Therefore, incorporation of pulse flours had 2 to 6 times greater minerals content than regular rice noodles. Novel rice noodle incorporated with chickpea flour had a higher fat content than lentil flour incorporations, ranged from 0.31 to 1.30 g/100 g DM. The higher fat content of chickpea flour substitution was attributed to chickpea flour had highest fat content of 2.77 g/100 g DM, but chickpea fat mostly is polyunsaturated fatty acids and could be reducing the risk of cardiovascular disease (Asif et al., 2013; Mudryj et al., 2014). In
addition, rice noodle incorporated lentil flour displayed very low-fat content and not much of a
difference with increasing substitution levels.

4.4.1 Starches and Dietary fiber content

For the major component of novel rice noodles, all novel rice noodles obtained reduced starch
content, but improvement in nutrition compared with regular rice noodles, particularly in dietary fiber
content. Rice noodle contained approximately 30 g/100 g DM higher amount of total starch (TS) content
than both chickpea and lentil flour. But pulse flours contained thirty to forty times higher resistant starch
(RS) content than rice noodles, and lentil flour had 1.45 g/100 g DM more resistant starch than chickpea
flour. Overall, both pulse flours are considered as high resistant starch foods (Murphy, Douglass, & Birkett,
2008). With increased incorporation of pulse flours, the TS and non-resistant starch (NRS) contents were
reduced, but RS contents were increased. The TS, NRS and RS contents of rice noodles incorporated with
pulse flours ranged from 68.4 (L50:R50) to 80.02 g/100 g DM (C15:R85), 66.75 (L50:R50) to 79.54
g/100 g DM (C15:R85) and 0.49 (C15:R85) to 1.64 g/100 g DM (L50:R50), respectively (Table 12). In
general, incorporations of chickpea flour exhibited higher TS and NRS, but lower RS than the
fortifications of lentil flour, the greater amount of RS obtained in lentil flour could explain this
observation and was consistent with the research of Chung, Liu, Hoover, et al. (2008). L30(F):R70 had
the highest TS (79.27 g/100 g DM), NRS (78.72 g/100 g DM) and lower RS (0.55 g/100 g DM) among all
the lentil flour incorporated rice noodles, which was mostly because sieving decreased RS content, as
lentil (F) had 1.19 g/100 g DM lower RS and lentil
(N) had 0.83 g/100 g DM higher RS in comparison with lentil flour. This finding showed RS might mainly
be present within the hull of lentil flour, which mostly did not sieve though the 80 mesh. Moreover, the
addition of psyllium positively affected the TS and RS content of novel rice noodles, as L30(P):R70
exhibited a minor increase in TS and RS than L30:R70. Psyllium are mostly composed by dietary fiber
(DF) and RS is considered as one type of DF, thus, the addition of psyllium caused a slight increase in RS
and result with higher amount of total starch.
Furthermore, pulse flour fortified rice noodles displayed improved DF compared to rice noodle. Lentil and chickpea flour contained 14.73 and 16.25 g/100 g DM more total dietary fiber (TDF) content than rice noodle, respectively. Chickpea flour contained higher TDF than lentil flour, especially with higher insoluble dietary fiber (IDF) than lentil flour. There was no significant difference (P < 0.05) of soluble dietary fiber (SDF) between the two pulse flours. Incorporation of pulse flour with rice noodle resulted in a significant increase in TDF with increased pulse flour concentrations, from 3.39 (L15:R85) to 8.89 g/100 g DM (C50:R50). Altogether, incorporation of chickpea flour exhibited higher TDF, SDF and IDF than the fortification of lentil flour. This finding could be related to chickpea flour containing 1.52 g/100 g DM more TDF than lentil flour. IDF and SDF of chickpea flour combined rice noodles ranged from 5.77 to 8.02 g/100 g DM and 1.27 to 3.27 g/100 g DM, respectively. Incorporation of lentil flour caused IDF and SDF to range from 4.43 to 7.08 g/100 g DM and 1.05 to 2.79 g/100 g DM, respectively. L30(F):R70 had the lowest IDF because lentil (F) had slightly reduced IDF than lentil flour. Sieving filtered out some of the hulls of lentil flour, which cannot be ground small enough to go through the sieve. But the hulls of the lentil flour contained 87% of DF, which could be proved by lentil (N) displaying 0.89 g/100 g DM higher IDF than lentil flour (Tosh & Yada, 2010). L30(P):R70 had the highest SDF of 1.81 g/100 g DM among all the rice noodles that incorporated with 30% lentil flour, due to the addition of 0.25% psyllium increasing the SDF, since psyllium contained about 70% SDF of its total constituents (Cappa et al., 2013).

Much Research has pointed out that Americans consume insufficient amount of DF of 13 to 17 g/d and 4.7 g/d for RS (Murphy et al., 2008; Warshaw, 2007), whereas the recommended intake is 25 to 38 g/d for DF and 5 to 6 g/d for RS (Behall et al., 2006; Warshaw, 2007). One of the main advantages of adding lentil and chickpea flour into rice noodles was to increase the DF including RS in the rice noodle products, since rice noodles are known to be high in starch. It is noted that high FD and RS2 food (i.e. pulses) corresponds to lowering glycemic and insulin response, weight management and improved digestive health (possibly to reduce the risk of colon cancer) (Warshaw, 2007). Therefore, the new rice noodle
products have the potential health benefits for obesity, diabetes, colon cancer and other dietary management. Consuming approximately 250 g of C50: R50 novel rice noodle or about 350 g L30(P):R70 already meet the required daily DF intake, while obtaining 25% and 15%, respectively of resistant starch needed daily. As a result, both pulse substituted rice noodles are a healthier choice to consume regularly.

4.4.2 Protein and amino acid composition

Richer protein content than rice noodles was another key beneficial characteristic of the novel pulse flours substituted rice noodles. The protein content of novel rice noodle incorporated with different substitutions of chickpea and lentil flour is listed in Table 13. Lentil and chickpea flour contained 16.53 and 16.10 g/100 g DM protein, respectively, much higher than rice noodle (~7.5 g/100 g DM). The protein content for three types of lentil flour were placed in the following order: lentil (F) > LF > lentil (N). Indeed, the protein contents of the novel rice noodles were raised with increasing incorporation of pulse flours. The incorporations of the chickpea flour caused the protein range from 9.05 to 13.09 g/100 g DM. While the fortifications of the chickpea flour were placed in following order: L50:R50 > L30(P):R70 > L30(F):R70 > L30:R70 > L15:R85. There was no significant difference (p < 0.05) in protein content between L30(F):R70 and L30:R70, but L30(P):R70 exhibited 0.37 g/100 g DM higher protein content than L30:R70. However, L30(P):R70 obtained slightly lower TAA, the difference might be contributed to the free flowing NH₃ that was detected by combustion nitrogen analyser, since the protein content was calculated based on N x 6.25. Hence, there was no significant difference in protein content of the three types of 30% lentil flour substitutions. This fact also could be explained by the ~1 g/100 g DM difference between the calculated TAA contents and the protein content measured, however, the overall trends were not influenced by this minor difference.

Pulses have substantial amounts of the essential amino acid (EAA) including lysine, arginine, leucine, and phenylalanine, as well as decent amounts of isoleucine, valine, histidine, and threonine, but short for sulphur containing amino acids, methionine and cysteine (Boye et al., 2010; Carvalho et al., 2013). However, cereals such as rice have higher amounts of the methionine and cysteine. Hence, novel
rice noodles that combine pulse and RF resulted in a superior amino acid profile that contains all essential amino acids in adequate amounts (Carvalho et al., 2013). These fortified rice noodle products could act as a primary food source for people eating gluten-free diets. Table 13 displays the amino acid composition of novel rice noodles that were made with various pulse flour substitutions. For the lentil flour fortifications, the EAA ranged from 5.07 to 6.88 g/100 g DM, which was slightly higher than chickpea flour fortifications ranging from 4.82 to 6.52 g/100 g DM. The recommended intake for a 70 kg adult of the EAA was 12.88 g/100 g daily (calculation was based on 184 mg/kg required EAA daily intake) (WHO/FAO/UNU, 2007), equal to consuming ~200 g of C50:R50 and ~230 g of L30(P):R70 novel rice noodle products. Also, the methionine together with cysteine of novel rice noodles were increased compared with pulse flour, but gradually decreased with increasing pulse substitution percentages from 0.63 to 0.47 g/100 g DM for chickpea flour fortifications and 0.61 to 0.45 g/100 g DM for lentil flour incorporations. This decrease could be attributed to the decrease in rice percentage within the novel rice noodle with gradually increasing pulse flour substitutions. On the other hand, compared to RN1 and RN2, with increased level of pulse flour, lysine, arginine, leucine, and phenylalanine increased, ranged from 0.42 to 0.79 g/100 g DM, 0.77 to 1.15 g/100 g DM, 0.71 to 0.97 g/100 g DM and 0.51 to 0.74 g/100 g DM, respectively for chickpea flour substitution. Whereas for lentil flour combinations, the lysine, arginine, leucine and phenylalanine also increased but to a greater extent than chickpea flour substitution, ranging from 0.48 to 0.89 g/100 g DM, 0.78 to 1.11 g/100 g DM, 0.72 to 1.02 g/100 g DM, and 0.56 to 0.78 g/100 g DM, respectively. Other amino acid improved as well, with increased pulse fortifications. Meanwhile, lentil flour substitutions all exhibited greater amino acid profile than chickpea flour substitutions, except chickpea flour incorporations had higher cystine than lentil flour incorporations. Overall, C50: R50 and L50: R50 displayed the most superior amino acid profile and were most suitable to sustenance from a healthy diet.
Table 12. Chemical composition of novel rice noodles blends with different pulse flours.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Protein</th>
<th>Ash</th>
<th>Fat</th>
<th>RS</th>
<th>NRS</th>
<th>TS</th>
<th>IDF</th>
<th>SDF</th>
<th>TDF</th>
</tr>
</thead>
<tbody>
<tr>
<td>RN1</td>
<td>7.61±0.02a</td>
<td>0.29±0.00a</td>
<td>0.54±0.01d</td>
<td>0.00±0.00a</td>
<td>85.96±0.12k</td>
<td>85.96±0.13i</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RN2</td>
<td>7.54±0.03a</td>
<td>0.39±0.01a</td>
<td>0.12±0.00a</td>
<td>0.11±0.00b</td>
<td>86.19±0.28k</td>
<td>86.30±0.30i</td>
<td>-</td>
<td>-</td>
<td>2.31±0.08a</td>
</tr>
<tr>
<td>lentil (F)</td>
<td>24.25±0.33j</td>
<td>1.96±0.05fg</td>
<td>0.81±0.02e</td>
<td>3.37±0.05j</td>
<td>49.96±0.16c</td>
<td>53.33±0.20b</td>
<td>11.49±0.34e</td>
<td>4.77±0.29f</td>
<td>16.26±0.32g</td>
</tr>
<tr>
<td>lentil (N)</td>
<td>23.45±0.11i</td>
<td>2.11±0.08g</td>
<td>1.01±0.05f</td>
<td>5.39±0.11i</td>
<td>47.95±0.35a</td>
<td>53.34±0.25b</td>
<td>13.25±0.35fg</td>
<td>4.57±0.30f</td>
<td>17.82±0.19hi</td>
</tr>
<tr>
<td>LF</td>
<td>24.07±0.05j</td>
<td>2.31±0.11h</td>
<td>0.93±0.08f</td>
<td>4.56±0.13k</td>
<td>48.45±0.18b</td>
<td>53.01±0.24b</td>
<td>12.36±0.19f</td>
<td>4.68±0.08f</td>
<td>17.04±0.11gh</td>
</tr>
<tr>
<td>CF</td>
<td>23.64±0.15i</td>
<td>1.26±0.19d</td>
<td>2.77±0.05g</td>
<td>3.11±0.13i</td>
<td>47.61±0.32ab</td>
<td>50.72±0.34a</td>
<td>13.94±0.21g</td>
<td>4.62±0.32f</td>
<td>18.56±0.11i</td>
</tr>
<tr>
<td>C15:R85</td>
<td>9.05±0.02b</td>
<td>0.89±0.00b</td>
<td>0.31±0.01c</td>
<td>0.49±0.01c</td>
<td>79.54±0.18j</td>
<td>80.02±0.19h</td>
<td>5.77±0.22b</td>
<td>1.27±0.12ab</td>
<td>7.04±0.25cd</td>
</tr>
<tr>
<td>C30:R70</td>
<td>10.61±0.02d</td>
<td>1.16±0.07c</td>
<td>0.65±0.02d</td>
<td>0.57±0.02d</td>
<td>73.43±0.45f</td>
<td>74.01±0.45e</td>
<td>7.16±0.24c</td>
<td>2.56±0.11d</td>
<td>9.72±0.35e</td>
</tr>
<tr>
<td>C50:R50</td>
<td>13.09±0.01g</td>
<td>1.60±0.07e</td>
<td>1.30±0.01h</td>
<td>1.39±0.03g</td>
<td>70.27±0.07e</td>
<td>71.66±0.05d</td>
<td>8.02±0.31d</td>
<td>3.27±0.16e</td>
<td>11.29±0.26f</td>
</tr>
<tr>
<td>L15:R85</td>
<td>10.05±0.03c</td>
<td>0.86±0.01b</td>
<td>0.15±0.01a</td>
<td>0.53±0.02cd</td>
<td>77.53±0.32h</td>
<td>78.06±0.04g</td>
<td>4.65±0.14a</td>
<td>1.05±0.04a</td>
<td>5.70±0.11b</td>
</tr>
<tr>
<td>L30(F):R70</td>
<td>11.91±0.09e</td>
<td>1.11±0.03c</td>
<td>0.20±0.01a</td>
<td>0.55±0.00d</td>
<td>78.72±0.37i</td>
<td>79.27±0.14h</td>
<td>4.43±0.29a</td>
<td>1.56±0.07bc</td>
<td>5.99±0.28b</td>
</tr>
<tr>
<td>L30(R70)</td>
<td>11.87±0.02e</td>
<td>1.17±0.09cd</td>
<td>0.29±0.01b</td>
<td>1.19±0.02e</td>
<td>75.66±0.10g</td>
<td>76.85±0.12f</td>
<td>5.44±0.13b</td>
<td>1.38±0.04ab</td>
<td>6.82±0.15c</td>
</tr>
<tr>
<td>L30(P):R70</td>
<td>12.24±0.04f</td>
<td>1.24±0.04d</td>
<td>0.27±0.02b</td>
<td>1.28±0.02f</td>
<td>76.58±0.04gh</td>
<td>77.86±0.05g</td>
<td>5.52±0.09b</td>
<td>1.81±0.22c</td>
<td>7.33±0.13d</td>
</tr>
<tr>
<td>L50:R50</td>
<td>14.23±0.09h</td>
<td>1.86±0.07f</td>
<td>0.36±0.00c</td>
<td>1.64±0.01h</td>
<td>66.75±0.26d</td>
<td>68.40±0.32c</td>
<td>7.08±0.28c</td>
<td>2.79±0.06d</td>
<td>9.87±0.26e</td>
</tr>
</tbody>
</table>

a-l Difference superscripts within the same column are significantly different by Duncan's multiple range test (p < 0.05). All values are expressed as g/100 g DM of samples, and are mean ± SD of three replicates. Abbreviation: IDF = insoluble dietary fiber, SDF = soluble dietary fiber, TDF = total dietary fiber, RS = resistant starch, NRS = non-resistant starch, TS = total starch.
Table 13. Amino acid composition of novel rice noodles blends with different pulse flour content. a

| Sample       | Valb | Metb | Ileb | Leub | Pheb | Lysb | Hisb | Argb | Thrb | Aspb | Serb | Glub | Glyb | Alab | Tyrb | Met+Cy | Phe+Tyr | EAA | TAA |
|--------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|-------|---------|-----|-----|
| FAOa         | 26   | 10   | 20   | 39   | -    | 30   | 10   | -    | 15   | -    | -    | -    | -    | -    | 4     | 15    | 25   | 184 |
| RN1          | 0.42 | 0.19 | 0.29 | 0.59 | 0.40 | 0.26 | 0.17 | 0.57 | 0.29 | 0.68 | 0.41 | 1.60 | 0.33 | 0.43 | 0.47  | 0.33   | 0.66 | 0.72 |
| RN2          | 0.42 | 0.15 | 0.28 | 0.59 | 0.40 | 0.26 | 0.17 | 0.59 | 0.29 | 0.69 | 0.41 | 1.60 | 0.34 | 0.43 | 0.48  | 0.34   | 0.64 | 0.74 |
| CF           | 0.83 | 0.01 | 0.76 | 1.40 | 1.12 | 1.36 | 0.50 | 1.72 | 0.76 | 2.33 | 1.07 | 3.81 | 0.79 | 0.85 | 0.12  | 0.36   | 0.13 | 1.48 |
| LF           | 1.05 | 0.00 | 0.91 | 1.57 | 1.11 | 1.55 | 0.54 | 1.76 | 0.89 | 2.74 | 1.22 | 4.22 | 0.93 | 0.98 | 0.10  | 0.63   | 0.10 | 1.74 |
| lentil (F)   | 1.04 | 0.00 | 0.89 | 1.59 | 1.16 | 1.56 | 0.54 | 1.78 | 0.88 | 2.74 | 1.20 | 4.22 | 0.92 | 0.98 | 0.10  | 0.69   | 0.10 | 1.84 |
| lentil (N)   | 0.97 | 0.00 | 0.83 | 1.48 | 1.04 | 1.48 | 0.53 | 1.65 | 0.86 | 2.61 | 1.16 | 4.00 | 0.91 | 0.95 | 0.10  | 0.60   | 0.10 | 1.64 |
| C15:R85     | 0.47 | 0.14 | 0.35 | 0.71 | 0.51 | 0.42 | 0.22 | 0.77 | 0.36 | 0.93 | 0.50 | 1.90 | 0.41 | 0.48 | 0.48  | 0.38   | 0.63 | 0.89 |
| C30:R70     | 0.52 | 0.13 | 0.41 | 0.80 | 0.59 | 0.56 | 0.26 | 0.89 | 0.42 | 1.12 | 0.58 | 2.16 | 0.45 | 0.53 | 0.41  | 0.38   | 0.54 | 0.98 |
| C50:R50     | 0.61 | 0.12 | 0.51 | 0.97 | 0.74 | 0.79 | 0.33 | 1.15 | 0.51 | 1.45 | 0.71 | 2.63 | 0.56 | 0.62 | 0.35  | 0.43   | 0.47 | 1.18 |
| L15:R85     | 0.53 | 0.14 | 0.38 | 0.72 | 0.56 | 0.48 | 0.25 | 0.78 | 0.37 | 0.97 | 0.53 | 1.96 | 0.43 | 0.51 | 0.47  | 0.38   | 0.61 | 0.94 |
| L30:F:R70   | 0.60 | 0.13 | 0.45 | 0.87 | 0.66 | 0.66 | 0.29 | 0.94 | 0.45 | 1.26 | 0.64 | 2.34 | 0.50 | 0.59 | 0.37  | 0.43   | 0.50 | 1.10 |
| L30:R70     | 0.61 | 0.13 | 0.46 | 0.88 | 0.59 | 0.63 | 0.28 | 0.94 | 0.46 | 1.29 | 0.65 | 2.37 | 0.52 | 0.59 | 0.37  | 0.40   | 0.51 | 0.99 |
| L50:R50     | 0.69 | 0.12 | 0.55 | 1.02 | 0.78 | 0.89 | 0.36 | 1.11 | 0.57 | 1.65 | 0.80 | 2.80 | 0.60 | 0.68 | 0.32  | 0.45   | 0.45 | 1.23 |

a Values are expressed as g/100 g DM of samples and are mean of three replicates. Abbreviation: Val = Valine, Met = Methionine, Ile = Isoleucine, Leu = Leucine, Phe = Phenylalanine, Lys = Lysine, His = Histidine, Arg = Arginine, Thr = Threonine, Asp = Aspartic acid, Ser = Serine, Glu = Glutamic acid, Gly = Glycine, Ala = Alanine, Cys = Cysteine, Tyr =Tyrosine, EAA = Essential amino acid, TAA = Total amino acid.
b Means essential amino acid.
c FAO/WHO/UNU Energy and Protein Requirements (WHO/FAO/UNU, 2007); values are expressed as mg/kg per day.
4.5 Effect of extrusion on TPC and TFC and their antioxidant activities

4.5.1 Total phenolic and total flavonoid content

Table 14 analyzed the influence of rice noodle with different proportion of chickpea and lentil flour substitutions on total flavonoid content (TFC) and total phenolic content (TPC). The estimated TFC and TPC of novel rice noodles was based on the measurements of chickpea and lentil flour obtained from the experiments and calculated with corresponding sample proportions. From the results, the two types of rice noodles (RN1 and RN2) had a minimal amount of TFC and TPC. Sieve through the mesh had a great influence on the TFC and TPC for lentil flour substituted rice noodles. Lentil (N) exhibited 2 times higher TFC and 4.7 mg GAE/g DM richer amount of TPC than lentil (F). The proportion of chickpea flour into rice flour affected TFC, and TFC increased with the increasing ratio of chickpea flour ranging from 1.86 to 4.33 mg RE/g DM, similar to the estimated values. Besides, with the growing ratio of lentil flour, these indexes increased, the same with the estimated values ranging from 1.55 to 5.18 mg RE/g DM. But the experimental results were somewhat lower than calculated values for the TFC. This difference could be attributed to thermal destruction during extrusion and drying process, as flavonoids were claimed to be heat sensitive. This characteristic of flavonoids has been confirmed with research of both Huang, Chang, and Shao (2006); Sharma, Gujral, and Singh (2012) that TFC of sweet potato and barley decreased upon thermal processing. It would be the same rule applying to the calculated TPC and experimental data. However, the experimental result showed there was a maximum up to 5 times (C15:R85) or 4 times (L15:R85) increase of TPC with all the pulse flour incorporated rice noodles compared with the expected values. The increase of TPC was only until 30% and the rate of increase reduced between 30% to 50% substitutions for both chickpea and lentil flour. This trend could be related to thermal processing causing the release of the phenolic acids and its derivatives (i.e. ferulic acid, diferulic acid, and p-coumaric acid) from the cell wall of the plant materials including pulses (Shih, Kuo, & Chiang, 2009). Moreover, the TFC and TPC contents of three types of 30% lentil flour substituted rice noodles were placed in the following order: L30(F):R70 < L30:R70 < L30(P):R70. The hulls with larger particle size could be the major reason
influencing the TFC and TPC, lentil (N) obtained the highest TFC and TPC among the normal lentil flour and lentil (F), which means the hull exhibited richer TFC and TPC than the cotyledon for lentils. This observation was in accordance with the research of Gujral et al. (2011), which showed that the hulled pulses contained higher TPC than the dehulled ones.

4.5.2 DPPH and FRAP

Table 15 presents the influences of different proportion of chickpea and lentil flour substitutions on 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activities and ferric reducing antioxidant power (FRAP) along with applied measurements of chickpea and lentil flour to calculate the expected values. We found that the RM and extruded rice noodle had almost no effect on DPPH and FRAP. Furthermore, lentil flour exhibited approximately 3 times greater DPPH and FRAP than chickpea flour and this observation was consistent with the conclusion of Padhi et al. (2016). The proportion of chickpea flour and rice flour affected DPPH and FRAP, with the increasing ratio of chickpea, these indexes increased from 0.91 to 1.11 μmol TE/g DM and 19.64 to 21.97 μmol Fe²⁺/g DM, respectively, which was similar to the trend of calculated values. It was also observed that DPPH was significantly positively correlated with TFC (r = 0.844, p < 0.01) and TPC (r = 0.707, p < 0.01) and this finding was confirmed by the findings of Soison et al. (2014). For DPPH, the experimental results were slightly lower than calculated values, maybe because of the decrease in TFC lowering the DPPH activity, but the increase of TPC could bring up the DPPH as well. Thus, the difference between expected and experimental was not noticeable.

Interestingly, the ratio of lentil flour had a larger influence than chickpea flour when blended into rice noodle. With the increase of lentil flour incorporation ratio, the content of DPPH and FRAP rose from 1.35 to 2.21 μmol TE/g DM and 19.96 to 36.38 μmol Fe²⁺/g DM, respectively. FRAP was positively correlated with TFC (r = 0.927, p < 0.01) and TPC (r = 0.612, p < 0.01), which was in agreement with the research of Padhi et al. (2016). Thus, the better antioxidant activity of lentil than chickpea flour substituted rice noodles was due to lentil flour having significantly richer TFC and TPC content of 2.92 mg RE/g DM and 5.58 mg GAE/g DM, respectively than chickpea flour according to Table 14. We also noticed the experimental value
was much lower than expected values. Although lentil flour exhibited higher DPPH and FRAP than chickpea flour and RM, the lentil flour incorporated rice noodles showed a much greater reduction, ranged from 18 to 34% than chickpea flour substituted samples, which ranged from 5 to 10% reduction compared with the expected values. This finding might suggest that lentil flour had higher reduction ratio than chickpea flour in antioxidant activity or reducing power after processing, which included thermal extrusion and drying. The influence of lentil flour whether sieving through the mesh or not was more noticeable when measuring the FRAP, but it had some influence on DPPH. The hull of lentil that contained larger particle size could enrich the content of DPPH and FRAP, which could be observed by lentil (F) having lower antioxidant activity than lentil (N). Furthermore, the addition of psyllium had positive effects on the antioxidant activity for both DPPH and FRAP, as L30(P):R70 had highest DPPH among all the lentil flour incorporated rice noodles and highest FRAP among all the 30% lentil flour substations. The psyllium added rice noodle exhibited richer TFC and TPC content than other two 30% lentil flour substituted rice noodles, which indicated that psyllium might have the ability to prevent reduction of antioxidant components such as TFC during thermal processing. All in all, L50:R50 and L30(P):R70 for lentil flour incorporation as well as C50:R50 for chickpea flour incorporated novel rice noodle had the best antioxidant activity among all the samples investigated and will be beneficial for human health with regular intake.
Table 14. TFC and TPC content of rice noodle incorporated with different pulse flours.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Estimated&lt;sup&gt;m&lt;/sup&gt;</th>
<th>Experimental</th>
<th>Estimated&lt;sup&gt;m&lt;/sup&gt;</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM</td>
<td>-</td>
<td>0.06±0.05a</td>
<td>-</td>
<td>0.05±0.00a</td>
</tr>
<tr>
<td>RN2</td>
<td>-</td>
<td>0.03±0.02a</td>
<td>-</td>
<td>0.04±0.01a</td>
</tr>
<tr>
<td>CF</td>
<td>-</td>
<td>14.8±0.48h</td>
<td>-</td>
<td>8.80±0.32cd</td>
</tr>
<tr>
<td>C15:R85</td>
<td>2.26</td>
<td>1.86±0.10c</td>
<td>1.35</td>
<td>7.23±0.34b</td>
</tr>
<tr>
<td>C30:R70</td>
<td>4.48</td>
<td>3.30±0.12d</td>
<td>2.67</td>
<td>8.29±0.18c</td>
</tr>
<tr>
<td>C50:R50</td>
<td>7.43</td>
<td>4.33±0.35e</td>
<td>4.42</td>
<td>8.79±0.50d</td>
</tr>
<tr>
<td>lentil (F)</td>
<td>-</td>
<td>12.80±0.28g</td>
<td>-</td>
<td>10.16±0.25e</td>
</tr>
<tr>
<td>lentil (N)</td>
<td>-</td>
<td>27.59±0.34j</td>
<td>-</td>
<td>14.80±0.47i</td>
</tr>
<tr>
<td>LF</td>
<td>-</td>
<td>17.72±0.21i</td>
<td>-</td>
<td>14.38±0.28i</td>
</tr>
<tr>
<td>L15:R85</td>
<td>2.70</td>
<td>1.55±0.07c</td>
<td>2.19</td>
<td>9.35±0.48d</td>
</tr>
<tr>
<td>L30(F):R70</td>
<td>3.88</td>
<td>1.05±0.14b</td>
<td>3.08</td>
<td>9.13±0.48cd</td>
</tr>
<tr>
<td>L30(R70)</td>
<td>5.35</td>
<td>3.27±0.12d</td>
<td>4.34</td>
<td>11.16±0.30ef</td>
</tr>
<tr>
<td>L30(P):R70</td>
<td>5.35</td>
<td>4.16±0.18e</td>
<td>4.31</td>
<td>12.40±0.11g</td>
</tr>
<tr>
<td>L50:R50</td>
<td>8.89</td>
<td>5.18±0.20f</td>
<td>7.21</td>
<td>13.58±0.04h</td>
</tr>
</tbody>
</table>

<sup>a-j</sup> Difference superscripts within the same column are significantly different by Duncan's multiple range test (p < 0.05). Values are mean ± SD of three replicates. Abbreviation: TFC=Total flavonoid content, TPC= Total phenolic content

<sup>k</sup> Values are expressed as mg rutin equivalent/g dry weight of tested samples (mg RE/g DM)

<sup>l</sup> values are expressed as mg Gallic acid equivalent/g dry weight of tested samples (mg GAE/g DM).

<sup>m</sup> The estimated values were based on the addition of measured TPC and TFC of pulse flours and RM before extrusion according to ratio listed in the table.
Table 15. DPPH and FRAP results of rice noodle incorporated with different pulse flours.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Estimated $^m$</th>
<th>Experimental</th>
<th>Estimated $^m$</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM</td>
<td>-</td>
<td>0.85±0.03a</td>
<td>-</td>
<td>18.69±0.96a</td>
</tr>
<tr>
<td>RN2</td>
<td>-</td>
<td>0.80±0.05a</td>
<td>-</td>
<td>19.23±0.84a</td>
</tr>
<tr>
<td>CF</td>
<td>-</td>
<td>1.32±0.09c</td>
<td>-</td>
<td>30.51±0.43e</td>
</tr>
<tr>
<td>C15:R85</td>
<td>1.05</td>
<td>0.91±0.02a</td>
<td>20.46</td>
<td>19.64±0.94a</td>
</tr>
<tr>
<td>C30:R70</td>
<td>1.10</td>
<td>1.05±0.06b</td>
<td>22.24</td>
<td>21.59±0.36b</td>
</tr>
<tr>
<td>C50:R50</td>
<td>1.16</td>
<td>1.11±0.05b</td>
<td>24.60</td>
<td>21.97±0.63b</td>
</tr>
<tr>
<td>lentil (F)</td>
<td>-</td>
<td>3.48±0.02f</td>
<td>-</td>
<td>61.04±0.71h</td>
</tr>
<tr>
<td>lentil (N)</td>
<td>-</td>
<td>4.39±0.03h</td>
<td>-</td>
<td>132.65±1.66j</td>
</tr>
<tr>
<td>LF</td>
<td>-</td>
<td>3.93±0.02g</td>
<td>-</td>
<td>85.97±0.73i</td>
</tr>
<tr>
<td>L15:R85</td>
<td>1.44</td>
<td>1.35±0.01c</td>
<td>28.78</td>
<td>19.96±1.88a</td>
</tr>
<tr>
<td>L30(F):R70</td>
<td>1.74</td>
<td>1.38±0.06c</td>
<td>31.39</td>
<td>23.51±1.09c</td>
</tr>
<tr>
<td>L30:R70</td>
<td>1.88</td>
<td>1.78±0.06d</td>
<td>38.87</td>
<td>25.59±0.50d</td>
</tr>
<tr>
<td>L30(P):R70</td>
<td>1.87</td>
<td>2.21±0.17e</td>
<td>38.86</td>
<td>31.62±0.67f</td>
</tr>
<tr>
<td>L50:R50</td>
<td>2.47</td>
<td>2.10±0.02e</td>
<td>52.33</td>
<td>36.38±0.60g</td>
</tr>
</tbody>
</table>

a-j Difference superscripts within the same column are significantly different by Duncan's multiple range test ($p < 0.05$). Values are mean ± SD of three replicates. Abbreviation: DPPH=DPPH radical scavenging activities, FRAP= Ferric reducing antioxidant power,

$^b$ values are expressed as μmol Trolox equivalent/g dry weight of tested samples (μmol TE/g DM).

$^c$ Values are expressed as μmol Fe (II) equivalent/g dry weight of tested samples (μmol Fe$^{2+}$/g DM).

$^d$ The estimated values were based on the addition of measured TPC and TFC of pulse flours and RM before extrusion according to ratio listed in the table.

4.6 Sensory evaluation (customer survey) of cooked rice noodles

Table 16 displays the sensory evaluation results of cooked novel rice noodles with various pulse flour ratios. Based on the many considerations including chemical composition, texture profile analysis and taste evaluation from the lab, C30:R70 and C50:R50 were selected for chickpea flour substitutions and L30(F):R70, L30:R70, and L30(P):R70 were chosen for lentil flour fortifications, to be assessed for sensory evaluations. The sensory evaluation involved 80 consumers filing a consumer survey using 9-point hedonic or category scale studying the sensory parameters of selected novel rice noodle samples and willingness to purchase (WTP) was measured based on a 5-point category scale (Figure 5). C50: R50 exhibited no significant difference ($p < 0.05$) from rice noodles (RN), except it
displayed a lower intensity of springiness (5.2) than rice noodle (6.7), but the overall acceptability (OA) was not significantly influenced (p < 0.05) by this slight decrease in springiness. OA was strongly positively correlated with all the tested parameters, liking of dry surface appearance (r = 0.961, p < 0.01), surface (r = 0.970, p < 0.01), taste (r = 0.984, p < 0.01), colour (r = 0.961, p < 0.01), as well as intensity of smoothness (r = 0.974, p < 0.01), chewiness (r = 0.945, p < 0.01), hardness (r = 0.928, p < 0.01) and springiness (r = 0.862, p < 0.05). Meanwhile, WTP was positively associated with OA (r = 0.991 p < 0.01). Moreover, we observed the yellowness of the chickpea flour substituted rice noodle had positive influences on the consumers’ liking of novel rice noodles. With increasing chickpea flour ratio, the yellowness increased, and the colour scores and dry surface appearance scores increased, especially the colour of C50:R50, which showed a higher score of 7.2 than rice noodles of 7.0, and this might be one of the reasons C50:R50 displayed a closer OA toward rice noodle.

In general, lentil flour substitutions exhibited significant reduced sensory scores on all parameters compared to chickpea flour substituted rice noodles and L30: R70 and L30(F):R70 were completed rejected by the consumers with 37% and 25% reduction in OA, respectively. Also, according to WTP result, participants would only seldom or close to never purchase L30: R70 and L30(F):R70 novel rice noodles (Figure 5). This rejection mainly corresponds to their coarse texture, unpleasant mouth-feel and off flavour compared to chickpea flour substituted novel rice noodles or RN. However, L30(P):R70 had best sensory result among the other two tested, which might relate to the addition of psyllium increasing the water absorption, a smoother surface and decreased hardness of the lentil flour substituted rice noodles. Also, the sensory parameters for lentil flour fortifications obtained similar trends with TPA result of chewiness, springiness, and hardness (Table 11). Even though L30(P):R70 had the best result for all the lentil flour substituted result noodles, there was still 16% decrease compared with rice noodle for overall consumer acceptability.

Based on the broad question collected, 26% participants pointed out health was one of the important factors that affected their willingness to purchase, while ~60% participants considered taste
was a most important factor influencing their WTP and OA for the innovative rice noodle product. Dietary need, price, and the novelty were also asked, but they did not or had only minimal influence on consumer’s WTP and OA. This result might due to the participants were mostly undergraduate student (15), 59 graduate students (51 Master and 8 PhD candidates) and 6 PhD graduates. They are highly educated and take account of the health factor as one of the most important factors when they purchase novel food products. Another interesting finding, there were 16 people who rarely (including rarely and 1-5 times a year) consume rice noodles, who had much better scores on novel rice noodles blended with pulse flours and easier to accept the novel rice noodles than the ones who regularly consume the rice noodle. This observation indicates the unique sensory characteristics of novel rice noodles could be expanding the marketability for people who are not so fond of traditional rice noodles. As a result, chickpea flour substituted rice noodle had the better sensory results than lentil flour substituted rice noodles, whereas C50:R50 had the best result of all the pulse substituted rice noodles and had a greater possibility to be accepted by the consumers. L30(P):R70 exhibited the best outcome from all the lentil flour fortified rice noodle samples evaluated, but there was still space for improvements.

Table 16. Sensory evaluation of cooked novel rice noodles with different pulse substitutions.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Dry</th>
<th>Surface</th>
<th>Taste</th>
<th>Colour</th>
<th>Smoothness</th>
<th>Chewiness</th>
<th>Hardness</th>
<th>Springiness</th>
<th>OA</th>
</tr>
</thead>
<tbody>
<tr>
<td>RN</td>
<td>7.1±0.87d</td>
<td>7.1±1.05c</td>
<td>6.6±0.93d</td>
<td>7.2±1.24c</td>
<td>7.4±1.34d</td>
<td>6.6±1.24c</td>
<td>6.6±1.08b</td>
<td>6.7±1.32d</td>
<td>6.8±0.87d</td>
</tr>
<tr>
<td>C30:R70</td>
<td>6.3±0.96cd</td>
<td>5.4±1.06b</td>
<td>5.7±0.96bc</td>
<td>6.0±1.03b</td>
<td>5.7±0.94b</td>
<td>6.2±1.06c</td>
<td>6.0±1.18b</td>
<td>5.2±1.49c</td>
<td>5.8±1.08cd</td>
</tr>
<tr>
<td>C50:R50</td>
<td>7.0±1.13d</td>
<td>6.9±0.79c</td>
<td>6.8±1.34d</td>
<td>7.3±1.09c</td>
<td>6.9±1.05cd</td>
<td>6.5±1.16c</td>
<td>6.3±1.25b</td>
<td>5.2±1.41c</td>
<td>6.6±1.20d</td>
</tr>
<tr>
<td>L30(P):R70</td>
<td>5.4±1.38b</td>
<td>5.2±1.13b</td>
<td>5.0±1.52b</td>
<td>5.5±1.56b</td>
<td>4.6±1.35a</td>
<td>4.8±1.59b</td>
<td>4.5±1.22a</td>
<td>4.4±1.68b</td>
<td>5.1±1.13b</td>
</tr>
<tr>
<td>L30:F:R70</td>
<td>4.4±1.33a</td>
<td>4.2±1.31a</td>
<td>3.8±1.39a</td>
<td>4.1±1.29a</td>
<td>4.2±1.03a</td>
<td>3.9±1.05a</td>
<td>4.1±1.07a</td>
<td>3.9±1.13a</td>
<td>4.3±1.42a</td>
</tr>
<tr>
<td>L30(R):R70</td>
<td>5.4±1.42b</td>
<td>5.4±1.39b</td>
<td>6.0±1.07cd</td>
<td>5.3±1.15b</td>
<td>5.7±1.44b</td>
<td>6.2±1.25c</td>
<td>6.1±1.27b</td>
<td>5.5±1.36c</td>
<td>5.7±1.38cd</td>
</tr>
</tbody>
</table>

a-d Difference superscripts within the same column are significantly different by Duncan's multiple range test (p < 0.05). All values are mean ± SD, n = 80. A 9-pt hedonic scale was used to measure for consumers’ liking for the dry surface, cooked noodle surfaces, taste, colour and OA. The intensity of smoothness, chewiness, hardness, and springiness ranging from low to high were measured with 9-pt category scale.
4.7 *In vitro* starch digestibility and pGI of cooked novel rice noodles

The *in vitro* starch digestibility and pGI of selected novel rice noodle samples in comparison with rice noodles is presented in Table 17. C50:R50 for chickpea flour and L30(P):R70 for lentil flour substitution were selected to measure the enzyme digestibility of starch in the novel rice noodles based on the result of sensory evaluations and consideration of health perspectives. We observed all the rice noodle samples displayed similar digestion patterns and almost identical digestion rate (Figure 6). C50:R50 exhibited the lowest digestion rate, followed with L30(P):R70, which had some reduced digestion rate in comparison with two rice noodle products (RN1 and RN2). This reduction in digestion rate was mainly attributed to different proportion of RDS, SDS and RS in the novel rice noodles. RDS ratio is one of the major effects on the rate of digestion in most foods as it leads to a rapid elevation in blood glucose concentration after intake of food high in carbohydrate (N. Singh, 2011). Hence, lower RDS result in a healthier diet. The reduction of RDS was more significant within the C50:R50, as this novel chickpea flour substituted rice noodle had ~10% reduction in RDS compared with rice noodles. However, the addition of pulse flours within the rice noodle did not significantly influence the SDS of novel rice noodle
or even had lower SDS than RN1 (Figure 7). RS results in several physiological effects that are beneficial for human health including decreasing rate of glucose released into the bloodstream, causing the reduction in glycemic and insulinemic postprandial responses after a meal, decreasing the risk of colorectal cancer and initiating hypocholesterolemic effects (Bravo et al., 1998). Both novel rice noodles measured had significant higher RS content of 9% for C50:R50 and 4% for L30(P):R70 than tested rice noodles. As a result, both pulse fortified rice noodles were healthier to consume than regular rice noodles, meanwhile, C50:R50 were better than L30(P):R70 with richer RS and lower RDS.

Rice varieties are known to have high GI value (Miller et al., 1992), but Lok et al. (2010) reported Jiangxi rice noodle had an intermediate GI value of 68, which was consistent with our result of 66 for both RN1 and RN2. The lower GI was related to extrusion process inducing reduction of molecular weight of both amylose and amylopectin, which produced shorter starch branches that form indigestible cross-link complexes, thus lowering the GI (Politz et al., 1994; Theander & Westerlund, 1987). The chickpea and lentil flour substitution all significantly reduced the pGI values by approximately 11% and 5%, respectively, based on the equation of Granfeldt et al. (1992). However, based on the equation from Goñi et al. (1997) the reduction was less significant of 7% to 3%, respectively compared to rice noodles (Figure 8). Although rice noodle already had a moderately low GI, pulse substitution could further reduce the pGI value, related to chickpea and lentil flour having low pGI values ranging from 48.9 to 56.1 and 41.5 to 41.6, respectively (Chung, Liu, Hoover, et al., 2008). Besides, we found that the decrease in pGI was mainly caused by the increase in RS within both novel rice noodles.

Low GI food has a positive impact on diabetes patients because it could reduce blood lipid levels and glucose slowly released into the blood leads to balanced insulin response (D. J. Jenkins et al., 2002). Additionally, low GI-diet also aids in weight management, preventing obesity by increasing chewing time and satiety (Mudryj, 2014). The novel rice noodle was safer to consume by people with diabetes as one of the staple food for the meal than other rice products, as boiled white rice had GI ranging from 80 to 102 (Gatti et al., 1987; D. Jenkins et al., 1981; Rahman, Malik, & Mubarak, 1992). Hence, the novel rice noodle with an intermediate pGI value is a better and healthier choice. However, not all the noodle
products substituted with pulses exhibit moderate low pGI. Pasta had pGI of 111, with 30 pea substitution reduced the pGI to 102, but still considered as high GI food (Marinangeli, Kassis, & Jones, 2009). Also, regular Focaccia had a pGI of 81 and pulse substituted focaccia had a reduced pGI of 75 (Fujiwara, Hall, & Jenkins, 2017). But it also needs to be noted, pGI was usually significantly higher than in vivo or actual GI value (Fujiwara et al., 2017). Therefore, the real GI values could be further reduced than presented pGI values in Table 17 and the fortified rice noodles with pulse substitutions had a superior ability to reduce blood glucose level compared with other pulse fortified high starch food such as focaccia or pasta.

Table 17. Starch fractions, hydrolysis kinetics and predicted glycemic index of novel rice noodle samples with different pulse flour substitution in compared to rice noodles.

<table>
<thead>
<tr>
<th>Samples</th>
<th>RDS (%)</th>
<th>SDS (%)</th>
<th>RS (%)</th>
<th>HI</th>
<th>pGI&lt;sup&gt;a&lt;/sup&gt;</th>
<th>pGI&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>RN1</td>
<td>62.06±1.27c</td>
<td>29.18±1.58a</td>
<td>8.76±0.55a</td>
<td>97.93±0.41c</td>
<td>65.76±0.25c</td>
<td>66.37±0.16c</td>
</tr>
<tr>
<td>RN2</td>
<td>65.41±0.85d</td>
<td>26.10±1.70a</td>
<td>8.49±1.56a</td>
<td>99.11±0.57d</td>
<td>66.48±0.35d</td>
<td>66.83±0.22d</td>
</tr>
<tr>
<td>C50:R50</td>
<td>55.04±1.40a</td>
<td>27.19±0.93a</td>
<td>17.78±1.03c</td>
<td>87.43±0.83a</td>
<td>59.33±0.51a</td>
<td>62.28±0.32a</td>
</tr>
<tr>
<td>L30(P):R70</td>
<td>61.27±0.49b</td>
<td>26.59±0.56a</td>
<td>12.14±0.87b</td>
<td>94.10±0.85b</td>
<td>63.41±0.52b</td>
<td>64.87±0.33b</td>
</tr>
</tbody>
</table>

<sup>a</sup>-d Difference superscripts within the same column are significantly different by Duncan's multiple range test (p < 0.05). Values are mean ± SD, n=4. Abbreviation: RDS = rapid digestible starch, SDS = slowly digestible starch, RS = resistant starch, HI = hydrolysis index, pGI = predicted Glycemic index

<sup>e</sup>pGI<sub>a</sub> calculated by Granfeldt et al. (1992): pGI<sub>a</sub> = 8.198+(0.862*HI)

<sup>f</sup>pGI<sub>b</sub> calculated by Goñi et al. (1997): pGI<sub>b</sub>=39.71+(0.549*HI)
Figure 6. Digestion rate during in vitro digestion of selected rice noodle samples.

Figure 7. Starch fraction percentages of in vitro digestion of selected rice noodle samples.

Figure 8. Predicted GI values of in vitro digestion of selected rice noodle samples.
Chapter 5. Summary and recommendations

In conclusion, Canadian chickpea and lentil flours could be incorporated into rice noodles up to 50% for chickpea substitutions and 30% for lentil substitutions. The cooking time was significantly reduced, with a slight but acceptable increase in cooking loss. Incorporating Canadian pulses into rice noodles improved its nutrition profile, including protein and dietary fiber contents, and produced a superior balanced essential amino acid profile, which provides the final product with significant improvements in essential amino acid content that benefit consumers. Since both rice and pulses are gluten free, fortified rice noodles prepared from Canadian pulses C50:R50 and L30(P):R70 could be beneficial for people with celiac disease and diabetes in comparison with other rice products. With increased resistant starch and slightly decreased rapid digestible starch, the pGI was decreased to 59 for C50:R50 and 63 for L30(P):R70, and both novel rice noodles were lower than regular rice noodle with a pGI of 67. Moreover, pulse fortified rice noodles exhibited enriched total flavonoid and phenolic content, which corresponds to improved antioxidant activities. L50:R50 and L30(P):R70 for lentil flour incorporated, as well as C50:R50 for chickpea flour incorporated rice noodle had the best antioxidant activity among all tested noodle samples. For the sensory evaluation, C50:R50 had similar sensory scores to the rice noodles and can be acceptable by the consumers. L30(P):R70 exhibited the best result from all the lentil flour substituted rice noodle samples evaluated, indicating the addition of 0.25% psyllium positively influenced the quality and sensory properties of rice noodles, but there was still space for improvements before putting into the market.

For the next step, in order to commercialize the novel rice noodles, optimal formulation will be investigated. Different Canadian lentil, chickpea and pea cultivars will be tested with the current formulation, to investigate their influences on the noodle qualities and a preliminary market assessment will be taken for the development of novel rice noodles. Also, pure chickpea starch noodle could be tested since the amylose content was similar to the rice noodle quality. Furthermore, chickpea flour showed higher pasting temperature and lower pasting properties compared with lentil flours, suggesting it could be used in high-temperature processing foods such as deep-frying. Hence, other food products such as
doughnuts could consider using chickpea flour as the main ingredient to produce more gluten-free food products. With success of providing a superior essential amino acid profile with novel rice noodles, other cereal based products or rice related products could be considered to incorporate pulse flour, to increase the intake of essential amino acid profile regularly.
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