Nutrient and specification enhancement of fortified Asian noodles by chickpea flour substitution and transglutaminase treatment

Lihong Han, Zhan-Hui Lu, Jiajia Zhang, Bipasha Chakravarty, Lanyi Jin, and Xiaohong Cao

Collaborative Innovation Center for Food Production and Safety, North Minzu University, Yinchuan, Ningxia, China; Guelph Research and Development Centre, Agriculture and Agri-Food Canada, Guelph, Ontario, Canada

ABSTRACT
Effects of supplementation of chickpea flour (CF) (10% and 20%) to wheat flour (WF) followed by Transglutaminase (TGase) treatment (0–1.2%) were investigated to synergistically boost nutritional and texture properties of Asian noodles. The results showed that CF supplementation diluted both gluten-forming proteins and starch content of the blend, resulting in the weak dough, high cooking loss, and poor sensory quality. However, TGase treatment at 0.4–0.8% dosage could effectively recover the dough structure by crosslinking, including CF proteins as evidenced by Mixolab, SDS-PAGE, and dynamic viscoelasticity. The latter also distinguished the distinct dough structure treated by TGase from the wheat gluten-network. SEM revealed the improved network matrix and well-embedded starch granules in raw and cooked noodles. The cooked noodles substituted with 10% CF with 0.4% TGase treatment had the lowest cooking loss and comparable sensory qualities to WF control (p < .05).

ARTICLE HISTORY
Received 25 August 2020
Revised 28 December 2020
Accepted 4 January 2021

KEYWORDS
Asian noodle; chickpea; protein; transglutaminase; cross-linking; quality

INTRODUCTION
Wheat-based Asian noodles have become popular globally in recent decades. As a staple food option, noodle products have become globally recognized food and are popular in more than 80 countries. Noodle industry supplies consumers all over the world with about 95.4 billion servings per annum. Noodle products are also perfect vehicles for the supplementation of functional ingredients and nutrients. Improvement of nutritional and functional quality of wheat-based noodles has been explored by mixing other grain flours to noodle dough, such as oat flour, oat bran, rye flour, defatted meal from soybean, and flaxseed and sunflower seeds. Wheat is particularly limited in the essential amino acids lysine and threonine, which is essential amino acids needed by children and infants. The high total protein, lysine, and folate content in pulse make it a perfect match for producing composite flours along with cereals such as wheat. Chickpea (Cicer arietinum L.) is a pulse rich in various nutrients and chickpea proteins are rich in all essential amino acids, especially lysine and threonine. Chickpea has also been reported to show various medicinal and therapeutic effects, including antihypertensive activity and antihyperglycemic activity. These advantages endow chickpea flour (CF) as a perfect supplementation to wheat flour (WF). Nonetheless, introducing nutritional and functional ingredients such as CF often shows negative impacts on the processing, textural, and sensory properties of the final products, mostly attributed to the dilution effect of gluten-forming proteins in the system.

Transglutaminase (TGase, EC2.3.2.13) has recently received substantial attention to improve the functional and textural properties of various proteins which lack or are limited in gluten-forming...
proteins,\textsuperscript{[16]} and also in noodle preparations.\textsuperscript{[17–20]} TGase catalyzes acyl-transfer reactions between an \(\varepsilon\)-amino group of lysine (acyl acceptors) and carboxamide groups (acyl donors) of glutamine residues, leading to the crosslinking of \(\varepsilon\)-(\(\gamma\)-glutamyl)-lysine, and thus results in the formation of a stable protein network via intra- and inter-molecular cross-linkages.\textsuperscript{[21–23]} Application of TGase to wheat gluten proteins would be of particular interest because of their high glutamine content (approximately one-third of the total amino acids).\textsuperscript{[21,24]} However, the low quantity of lysine in wheat protein limits its value as an amine donor substrate.\textsuperscript{[23]}

So it is proposed that supplementing chickpea flour to wheat flour followed by appropriate TGase treatment would synergistically result in several positive effects not only on the processing quality and textural improvement in the resulting Asian noodle products but simultaneously provide nutritional benefits of lysine and threonine fortification and other nutritional enhancements that occur in chickpea flour. Based on these evidence, the objectives of this study were to investigate the effects of supplementation of CF to WF followed by TGase treatment at various dosages (0, 0.4 0.8, and 1.2%, flour base) on the flour physicochemical properties, and also on dough mixing behavior, noodle-making performance, and the cooking and sensory quality of the resultant noodles. The outcome of this work would provide practical and healthy solutions for producing high-quality Asian noodles without the use of any exogenous additives other than TGase.

**MATERIALS AND METHODS**

**Materials**

A commercial standard wheat flour (WF) (the content of dry gluten is 13.6%, and the gluten index is 93%) milled from cultivar Henong 6049 (grown in 2018, Hebei, China) with passing through 100 mesh sieve was obtained from Xinhua Department Store Co., Ltd. Chickpea flour (CF) was prepared by pulverizing the chickpea seeds (grown in 2018, Xinjiang, China) with a cyclone mill (Chopin Technologies, Villeneuve-La-Garenne, France) and passing through a 100 mesh sieve (WQS, Shanghai Science Instrument Co. Ltd. Shanghai, China). The yield of CF is approximately 89.28%. Transglutaminase (TGase, 100 U/g) was obtained from Yiming Biological Products Co. Ltd. (Jiangsu, China). All other chemicals used were of analytical grade and double-distilled water was used.

**Blend of WF and CF**

WF and a variable proportion of CF (0, 10% and 20%, wheat flour basis, w/w) were fully incorporated using a sample mixer (MR10L; Chopin, Tripette et Renaud, Paris, France). The mixed flours were then tightly sealed and stored in a dry and dark place.

**Element composition analysis**

WF, CF, and mixed flours were analyzed by standard AOAC methods\textsuperscript{[25]} for the content of moisture (AOAC 925.10), protein (AOAC 992.15), ash (AOAC 923.03), fat (AOAC 922.06), and total dietary fibre (AOAC 991.43). Total carbohydrates were calculated as the difference (carbohydrate \% = \[100 - \text{moisture }\% - \text{protein }\% - \text{fat }\% - \text{ash }\%\)).

**Mixolab behavior of flour blends**

The mixing behavior of the flour samples was investigated using a Mixolab analyzer (Chopin Technologies, France) with the Chopin\textsuperscript{+} protocol [Chopin Applications.26] Dough weight was kept constant at 90 g. After an initial mixing at 80 rpm/min for 8 min at 30°C, the dough was heated to 90°C at 4°C/min and held at 90°C for 7 min, and then cooled to 50°C at 4°C/min followed by mixing at 50°C for 5 min. The parameters obtained from the curve were: water absorption (the percentage of water
required for the dough to produce a torque of 1.1 Nm, %); dough development time (the time to reach the maximum torque at 30°C, min); stability (the elapsed time at which the torque produced are kept at 1.1 Nm, min); \(C_2\) (or minimum torque, measure mechanical weakening of protein, Nm); \(C_3\) (the maximum torque produced during the heating stage, measures starch gelatinization, Nm); and setback (the difference between the torque produced after cooling at 50°C and the torque after the heating period, measures starch retrogradation, Nm).

**Dough and noodle preparation**

The flour blends (100 g) were prepared by mixing the CF with WF at a ratio of 10:90 and 20:80 (CF:WF, w/w), respectively, in a mixer equipped with a stirring paddle for 5 min (National Mfg., Lincoln, NE). The prescribed amount of TGase (0%, 0.4%, 0.8%, and 1.2% w/w, flour basis) was dissolved in 40 mL of distilled water and then mixed with the flour blend in the mixer for 10 min to form a dough. The dough was rounded, covered with wrap film, and allowed to rest at 40°C for 2 h.

The rested dough was first sheeted manually to 3 mm in thickness with a rolling pin and was then sheeted successively by using a noodle maker (Yongkang kangmeijia food machinery Co. Ltd, Zhejiang, China). The sheeting sequence was as follows: pass through gaps 1 and 2 successively, double fold, and again pass through gaps 1 and 2. This sequence was conducted 3 times, followed by a further pass through gaps 3 and 4 to achieve a final sheet thickness of 2 mm. There was no resting period between sheeting steps, and dough was sheeted in the same direction each time.

A disk-shaped dough piece with a diameter of 20 mm was cut from the centre of the sheet using a stainless-steel cylindrical sampler and oscillatory measurements were conducted immediately. The remaining dough sheet was slit through a noodle cutter attachment to obtain noodle strands with 6 mm width and 5 cm length. The morphological structure of the noodle samples was investigated using a scanning electron microscope (SEM). A portion of noodle strands was dried at 40°C for 12 h, ground and passed through a 100 mesh sieve for the measurements of protein electrophoretic pattern and pasting properties by Rapid Visco Analyzer (RVA). Remaining noodle strands were used to determine cooking and sensory properties.

**Dynamic viscoelasticity of dough**

Dynamic viscoelasticity of the dough samples was measured in dynamic shear mode using a stress-controlled rheometer [AR1500ex, TA Instruments, New Castle, DE, USA] as described by, \(^{[19]}\) operated with a parallel-plate geometry with a 20 mm diameter at a 3 mm gap. The rim of the dough sample was coated with silicon oil [KF-96-20CS, Shin–Etsu Chemical Co. Ltd., Tokyo, Japan] to prevent evaporation during the measurement. Dynamic frequency sweep tests from 0.01 to 10 Hz were conducted to determine storage modulus (\(G'\)), loss modulus (\(G''\)), and loss tangent (\(\tan \delta = G''/G'\)) against frequency (\(\omega\)). Each measurement was performed in triplicate at 30°C.

The overall structure was evaluated by comparing plots of the complex dynamic viscosity (\(\eta^*\)) as a function of frequency (\(\omega\)), which showed the same frequency dependence as \(G'\) and \(G''\). The \(\eta^*\) is a more convenient indicator of overall structure because it combines both modulus: \(\eta^* = [(G')^2 + (G'')^2]^{1/2}/\omega^{[24]}\). Logarithmic plots of \(\eta^*\) vs \(\omega\) were fitted to power law equation with respect to frequency (\(\eta^*(\omega) = a^*\omega^{-b^*}\)). The derived parameters (log \(a^*\) and \(b^*\)) and the square correlation coefficient (\(R^2\)) for the fit was obtained.

The value of log \(a^*\) represents the magnitude of the viscoelastic functions, i.e., is related to the system consistency. The \(b^*\) parameter reflects the type of gel structure by the dependence of the viscoelastic functions on frequency, i.e., is related to the type of structure built up by the system molecules.\(^{[28]}\)

**Morphological properties of noodle samples**

The morphological structure of the noodle samples was investigated using a scanning electron microscope (SEM) (Hitachi-S-3400 N, Hitachi Ltd., Tokyo, Japan). Noodle samples were fixed in
2.5% glutaraldehyde for 4 h and rinsed with 0.1 mol/L phosphate buffer followed by a secondary fixation in 1% osmium tetroxide solution for 2.0 h. Then, the samples were submerged in 30%, 50%, 70%, 90%, and 100% of the graded ethanol series to achieve complete dehydration. Finally, noodle samples were vacuum freeze-dried and mounted on a silver specimen holder, and then sputter-coated with gold in a vacuum evaporator (Hitachi-E-1010 ion beam-sputtering instrument, Tokyo, Japan) with a 50 s coating time. Finally, the processed samples were observed at a magnification of 500× and an acceleration voltage of 15 kV.

**Protein electrophoretic pattern of noodle samples**

The enzymatic-crosslinking effect by TGase treatments was investigated by sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE).\(^{[21]}\) To extract proteins from noodle samples, a buffer (1.0 mL) containing 62.5 mM Tris–HCl (pH 6.8), 10% (v/v) glycerol, 2% (w/v) SDS, 0.01% (w/v) bromophenol blue, and 3% (v/v) β-mercaptoethanol was added to 50 mg ground noodle sample. The mixture was shaken for 2.5 h, heated in a boiling water bath for 5 min, and then centrifuged at 3000 × g for 5 min. After that, the supernatant (10 μL) was loaded into the electrophoresis well of the gel slab. SDS-PAGE analysis, with a molecular weight marker of PageRuler\(^{TM}\) pre-stained protein ladder (Fermentas, St. Leon-Rot, Germany), was carried out in 12% separating gel (pH 8.8) with 4% stacking gel (pH 6.8) at 10 mA. Coomassie Brilliant Blue G-250 (0.25%, w/v) in 50% methanol and 10% acetic acid, and a solution containing 5% methanol and 7.5% acetic acid were used to stain and de-stain the gel, respectively. Protein subunits were quantified (Relative quantification) using Image Lab 3.

**Pasting property of noodle samples**

A Rapid Visco Analyzer (RVA) (Newport Scientific Pvt. Ltd., Australia) was used to measure the pasting properties of dried raw noodles. Three grams of ground noodle were dispersed into 25.0 mL of distilled water in an aluminium canister. The sample was held at 50°C for 3 min for even distribution, heated to 95°C in 7.5 min, and then held at 95°C for 5 min, followed by cooling to 50°C in 7.5 min, and then held at 50°C for 2 min. The rotating speed was maintained at 160 rpm. The RVA curves were evaluated in terms of peak, trough, breakdown, final, and setback viscosities by the attached software (Thermocline for Windows, version 3.0).

**The color of noodle**

**Color, cooking, and sensory qualities of noodles**

The color of flesh noodle samples was measured using A CR-410 Chroma meter (Konica Minolta, Japan) equipped with D50 illuminant in a granular material sample holder. Twenty-five grams of the noodle samples were cooked in 500 ml of boiling water until the disappearance of the white core in the central portion of the noodle when pressed between two glass plates. The cooking water was collected and evaporated at 98°C to constant weight. Cooking loss was reported as the ratio of the residual weight of the cooking water to the weight of the noodle (dry weight base). The sensory quality of the cooked noodles was evaluated by quantitative descriptive analysis [QDA] method using a 10-point hedonic scale described by Fu et al.\(^{[29]}\) Eight panelists was selected from staffs who regularly consume Asian noodles and trained by the standard procedure to obtain instructions and the intensities of the attributes varying among the samples being evaluated. The training continued until all panelists were in accordance with the rating levels, and capable of reproducing consistent judgments among each session. The attributes assessed were chewiness, springiness, integrity, mouth-feel, and total score. The score for each parameter of the WF control noodle was set at 7.0.
**Statistical analysis**

Samples were tested in triplicate. Statistical analyses [t-test and one-way analysis of variance, ANOVA] were performed using SAS (Version 9.1 for Windows, SAS Institute Inc., Cary, NC, USA). When appropriate, the difference among means was determined using Tukey’s post hoc test, except that the Dunnett method was used for multiple comparisons of the CF-supplemented and TGase-treated samples to the WF control. Pearson correlation coefficients and principal component analysis (PCA) were performed on centred and standardized data to elucidate the relationships among variables and to group samples. Statistical significance was set at the 5% level of probability.

**RESULTS AND DISCUSSION**

**Elements content of WF and CF**

The element compositions of WF, CF, and mixed flours are given in Table 1. Compared with WF, CF had nearly double the amount of protein (p < .001), ash (p < .01), total dietary fiber (p < .01), and four-fold amount of fat (p < .001). Correspondingly, the total carbohydrate of CF (57.5%) was significantly lower than WF (74.8%) (p < .001). Similar results have been reported by others.[30,31] Supplementation of 20% CF to WF noodle formula significantly enriched the nutritional properties of the resultant products, especially protein (p < .01), fat (p < .05), and total dietary fiber (p < .01). However, both gluten-forming proteins and total starch in the flour blends would be diluted, and hence significant impacts on dough mixing properties, cooking and textural properties would be expected.

**Mixolab behavior**

Effect of CF supplementation

Mixolab parameters of WF control and CF-supplemented flours are shown in Table 2. The WF control required 59.3% of the water and 1.4 min of mixing to reach a torque of 1.11 Nm as defined by Mixolab [Chopin Applications.26] Supplementing 10% or 20% CF to WF led to a slight increase in water absorption whereas it nearly tripled the development time, followed by lower values of C2, C3, and dough stability but with higher setback than those of the WF control. The effect was more significant for 20%-supplemented flour blend (Table 2).

Mixolab parameter C2, stability and development time reflects gluten protein properties in a wheat dough system while the parameter C3 and setback measure the gelatinization and retrogradation of starch fraction, respectively, Chopin Applications.[26] Therefore, the above changes induced by CF supplementation especially by 20% CF would be directly attributed to: 1) the two dilution effects on either gluten protein or total starch amount in the blends as mentioned above; and 2) the increase in total protein, fat, and fibre content in the blends would also play important roles. On the one hand, less gluten proteins in the blends weakened the gluten network as indicated by the decreased C2 (measures gluten protein weakening). On the other hand, higher total proteins increased water absorption and development time. Except that, the dilution in total starch of the blends induced decrease in C3.

Table 1. Element composition of chickpea flour (CF) and wheat flour (WF) (g/100 g).

| Element composition | WF     | CF     | WF+10%CF | WF+20%CF |
|---------------------|--------|--------|----------|----------|
| Moisture            | 8.9 ± 0.3 | 8.6 ± 0.4 | 8.8 ± 0.6 | 8.9 ± 0.4 |
| Protein             | 13.0 ± 1.0 | 25.0 ± 1.1*** | 14.3 ± 0.9 | 17.8 ± 1.2** |
| Ash                 | 1.1 ± 0.2 | 2.8 ± 0.4** | 1.42 ± 0.3 | 1.58 ± 0.5 |
| Fat                 | 1.1 ± 0.3 | 4.4 ± 0.4*** | 1.39 ± 0.5 | 1.87 ± 0.4* |
| Total carbohydrate  | 74.8 ± 1.0 | 57.7 ± 1.1*** | 73.6 ± 0.9 | 71.4 ± 1.0** |
| Total dietary fiber | 0.8 ± 0.1 | 1.7 ± 0.3** | 0.91 ± 0.5 | 1.01 ± 0.1* |

Values are indicated as means ± SD of 3 replications.

Values with * (p< 0.05), ** (p< 0.01), or *** (p< 0.001) are significantly different among WF, CF and mixed flours by t-test.
Table 2. Mixolab parameters, dough rheological, structural, and pasting properties of flour blends of wheat flour (WF) and chickpea flour (CF) treated by transglutaminase (TGase).

| Flour blend      | WF (control) | WF+10% CF | WF+20% CF | WF+10% CF | WF+20% CF |
|------------------|--------------|-----------|-----------|-----------|-----------|
| TGase (%)        | 0            | 0.4       | 0.8       | 1.2       | 0.4       | 0.8       | 1.2       |
| **Mixolab parameters** |              |           |           |           |           |
| Water absorption (%) | 59.3 ± 0     | 59.5 ± 0 c | 58.1 ± 0 b | 57.3 ± 0 c | 56.7 ± 0 c | 60.3 ± 0 a*** | 60.2 ± 0 a*** | 59.3 ± 0 b*** | 59.0 ± 0 b*** |
| Development time (min) | 1.4 ± 0.21   | 3.65 ± 0.14 a | 3.54 ± 0.12 a | 3.7 ± 0.04 a | 3.35 ± 0.39 a | 3.35 ± 0.25 a | 3.48 ± 0.15 a | 3.57 ± 0.09 a* | 3.58 ± 0.49 a |
| Stability (min) | 8.15 ± 0.45  | 7.47 ± 0.09 b | 7.83 ± 0.5 a | 7.48 ± 0.36 b | 7.26 ± 0.46 b | 5.06 ± 0.08 c*** | 5.59 ± 0.02 b*** | 6.6 ± 0.25 a* | 3.6 ± 0.49 d*** |
| C₂ (Nm)        | 0.49 ± 0     | 0.4 ± 0 a  | 0.39 ± 0 a | 0.4 ± 0 a | 0.4 ± 0 a | 0.27 ± 0 c*** | 0.31 ± 0.01 b*** | 0.31 ± 0 b*** | 0.34 ± 0.01 a*** |
| C₃ (Nm)        | 1.74 ± 0.02  | 1.68 ± 0.01 c | 1.77 ± 0.01 b | 1.77 ± 0.03 b | 1.85 ± 0.05 a | 1.55 ± 0.01 b*** | 1.43 ± 0.01 d*** | 1.51 ± 0.01 c*** | 1.57 ± 0.01 a*** |
| Setback_MixLab | 1.02 ± 0.05  | 1.56 ± 0.01 b | 1.73 ± 0.01 a | 1.38 ± 0.07 c | 1.28 ± 0.08 c | 1.46 ± 0 b*** | 2.02 ± 0.01 a*** | 1.48 ± 0.07 b | 1.25 ± 0.13 c |
| **Dynamic viscoelasticity** |              |           |           |           |           |
| Log a*         | 5.57 ± 0.01  | 5.62 ± 0.01 c | 5.85 ± 0.02 b | 5.95 ± 0.02 a | 5.21 ± 0.06 b*** | 6.12 ± 0.02 a** | 6.15 ± 0.02 a*** | 6.1 ± 0.01 a*** |
| b*             | 0.84 ± 0     | 0.84 ± 0 b | 0.89 ± 0 a | 0.89 ± 0 a | 0.9 ± 0 a | 0.8 ± 0 c*** | 0.9 ± 0 b*** | 0.9 ± 0 a* | 0.9 ± 0 a* |
| **Pasting property** |              |           |           |           |           |
| Peak viscosity | 1420 ± 13    | 1461 ± 22 c | 1545 ± 15 ab | 1588 ± 15 a | 1536 ± 23 b | 1104 ± 5 b*** | 1095 ± 1 b*** | 1152 ± 23 a*** | 1074 ± 12 b*** |
| Trough viscosity | 992 ± 20    | 1005 ± 3 b | 1085 ± 15 a | 1111 ± 25 a | 1084 ± 15 a | 793 ± 13 c*** | 829 ± 3 ab*** | 843 ± 13 a*** | 804 ± 13 bc*** |
| Breakdown | 441 ± 21    | 454 ± 23 a | 460 ± 22 a | 477 ± 12 a | 452 ± 9 a | 311 ± 11 a*** | 266 ± 3 b*** | 309 ± 11 a*** | 270 ± 3 b*** |
| Final viscosity | 2080 ± 32 | 2122 ± 37 a | 2155 ± 15 a | 2179 ± 43 a | 2124 ± 22 a | 1654 ± 17 a*** | 1571 ± 9 b*** | 1579 ± 25 b*** | 1511 ± 25 c*** |
| Setback_RVA | 1101 ± 39   | 1126 ± 36 a | 117 ± 7 ab | 1067 ± 22 b | 1040 ± 8 b | 861 ± 5 a*** | 742 ± 12 b*** | 736 ± 13 c*** | 707 ± 12 c*** |

Values are presented as the mean ± SD, n = 3. Values within a row at the same addition level of chickpea flour followed by a different lower-case letter are significantly different by ANOVA followed a Tukey’s test (p < 0.05); At a same TGase level, * (p < 0.05), ** (p < 0.01), or *** (p < 0.001) indicates significantly different between “WF+10%CF” and “WF+20%CF” by t-test; Almost any treatment showed highly significant difference to control (WF) by ANOVA followed by a Dinette test (p < 0.001), except in most cases for the sample “WF+10% CF” (i.e. trough viscosity, breakdown, final viscosity, setback_RVA, log a* and b*); and in a few cases for the sample “WF+10% CF treated by various dosage of TGase” (i.e. C₂, breakdown, final viscosity and setback_RVA). The results were not shown for clarity.

The values of a* are equal to η* at 1 rad/s, at room temperature, frequency range from 0.01 to 10 rad/s; The coefficient (R²) of power law of complex modulus (η*) was > 0.999 in all cases.
However, the increase in setback by CF supplementation, which measures starch retrogradation, might be interpreted by the weakened gluten network which allowed more freedom for starch granule swelling and thus more retrogradation. Furthermore, chickpea starch was reported to have a higher setback than that of wheat starch.[32]

Effect of TGase treatment: As shown in Table 2, the weakened dough property caused by CF addition was significantly amended by TGase treatments, especially for the 20% CF-supplemented flour \( (p < .001) \). TGase treatment at an increasing dosage significantly increased \( C_2 \) of the dough containing 20% CF. The highest dough stability was achieved by an optimal dosage from 0.4% to 0.8%. In general, water absorption decreased with the increasing TGase dosage, regardless of the addition ratio of CF. Similar results have been reported on TGase-treated wheat-buckwheat flour, [33] wheat-sweet potato flour, [34] and oat flour. [27]

Development time is relevant to the necessary time to hydrate all the compounds in flour during mixing. The critical component in the mixing stage is protein. [19] Interestingly, TGase treatment at various dosages did not show any significant effect on dough development time, either in 10% CF or 20%, CF-supplemented flour (Table 2). Similar results were previously reported. [19,35] Apparently, it is the inhomogeneity induced by CF supplementation that dominated dough development. Development time was less than 4 min for all the samples (Table 2). Probably the protein crosslinking catalyzed by TGase was not yet initiated within this short time span.

It appears that an increasing trend of \( C_3 \) with a decreasing trend of setback exists with the increasing dosages of TGase treatment (Table 2), which could be an indirect effect arising from the strengthened matrix surrounding the starch granules, including protein denaturation during the heating and cooling stages in MixoLab, and also includes the protein crosslinking by TGase, which was also proposed by. [19] The increase in toughness of the matrix could contribute to not only the increase in \( C_3 \) by inhibiting the swelled starch granules from bursting but also the decrease in setback by blocking the recrystallization of gelatinized starch molecules (inhibition of starch retrogradation). In other words, TGase treatment introduced antiretrogradation effect on starch by the enhanced protein matrix surrounding the starch granules.

**Dynamic viscoelasticity**

Effect of CF supplementation: Dynamic viscoelasticity \( (G', G'', \text{ and tan } \delta) \) and derived complex dynamic viscosity \( (\eta^*) \) of CF-supplemented dough samples followed by TGase treatment is shown in Figure 1. Higher storage modulus \( (G') \) than loss modulus \( (G'') \) in the whole frequency range was observed, which resulted in \( \text{tan } \delta \text{ value } <1 \) in all samples and signified that the elastic feature of the samples was more prominent than the viscous characteristics. At a specific frequency, \( G' \) and \( G'' \) values were similar between 10% CF-supplemented dough and the WF control dough. However, these values were significantly decreased while \( \text{tan } \delta \text{ largely increased when 20\% of CF was supplemented} \) (Figure 1) \( (p < .05) \). Probably the continuous gluten network might be less interrupted by 10% CF addition, whereas partially discontinued by 20% CF addition. This result is consistent with that of Mixolab (Table 2) and was also reported by Jia et al., [15] and suggests that CF supplementation up to 20% level significantly weakened the resultant dough.

Effect of TGase treatment: As shown in Figure 1, the weakened dough by CF-supplementation was significantly recovered by TGase treatment, with the \( G' \) value even higher than that of control in all the cases \( (p < .05) \). The decrease in \( \text{tan } \delta \) of TGase-treated dough in any dosage was also indicative of strengthened protein network. In any dosage, TGase treatment significantly decreased Tan \( \delta \) \( (p < .05) \), with more reduction seen in 20% CF dough (Figure 1). A similar result was reported for buckwheat flour-supplemented dough treated by 0.5–1.5% TGase by Han et al. [33] In this study, the maximum of \( G' \) and \( G'' \) are obtained at 0.4% TGase for the dough supplemented with 10% CF, and 0.8% TGase for the dough with 20% CF, respectively (Figure 1). TGase treatment was more effective to amend the more weakened dough structure caused by 20% CF supplementation, which could be solely attributed to the higher lysine amount than that in 10% CF supplementation. Lysine appeared to be the limiting
factor in these WF/CF flour blends for TGase-catalyzed polymeric linkage through isopeptide bonds between lysine and glutamine residues. These results suggested that lysine residues of CF protein involved in TGase catalyze cross-linking.

Nonetheless, TGase treatment at 1.2% appeared to be over-dosed in this study (Figure 1). Decreases in $G'$ and $G''$ of CF-supplemented wheat dough treated by over-dosed TGase treatment were also reported by, and the authors suggested that excessive cross-linking among proteins induced by 1.2% TGase and an increased number of enzyme filler might restrict the formation of hydrogen bonds between protein and starch and eventually decrease pasting viscosities.

Complex dynamic viscosity: A linear decrease of complex dynamic viscosity ($\eta^*$) with frequency is observed in Figure 1. The derived parameters ($\log a^*$ and $b^*$) for the fit of $\eta^*$ to the power-law equation with respect to frequency are shown in Table 2. In all cases, the coefficient of determination ($R^2$) for the fit of $\eta^*$ was 0.999, indicating a good fit. The 10% CF-supplemented dough showed comparable $\log a^*$ and $b^*$ to the WF control ($p > .05$) but was significantly different to 20% CF-supplemented dough ($p < .001$), suggesting a similar system consistency and structure between 10% CF-supplemented dough and the control (i.e., continuous gluten-network filling with wheat starch and/or CF flour), but a distinctly decreased system consistency, and structure with 20% CF-supplemented dough (i.e., partially discontinued wheat gluten network interrupted by 20% CF). This structural difference revealed by dynamic viscoelasticity is supportive to the weak dough property demonstrated by Mixolab (Table 2).

TGase treatment at any dosage in this study significantly increased both $\log a^*$ and $b^*$ of CF-supplemented doughs ($p < .01$), indicating a significant increase in system consistency and structural heterogeneity, and suggested that, distinct to the wheat gluten network, CF proteins were involved in the cross-linking by TGase and formed an intertwined network among WF and CF proteins.

Morphological properties of noodle samples

Effect of CF supplementation: SEM images of raw and cooked noodle samples is shown in Figure 2 (A-J). In raw noodle samples (left panel of Figure 2), starch granules were evenly distributed and embedded in the raw noodle matrix, showing a well-mixed dough. The starch granules were surrounded by a sticky gluten network in the control sample (Figure 2A), whereas they were loosely wrapped in the matrix of dough made from 10% CF (Figure 2C) and more obviously loose in 20% CF samples (Figure 2E). This visual difference could be another proof of gluten dilution effect by CF addition as discussed above.

After cooking (right panel of Figure 2), most of the starch granules were still visible on the surface of cooked control noodles (Figure 2B), whereas the majority of the starch granules were lost and left hollows and voids on the surface of CF-added samples, showing a honeycomb-like structure (Figure 2D and 2F). This observation was well-supported by the highest cooking loss for 20% CF-added sample (11.3%) and higher cooking loss for 10% CF-added sample (6.1%) compared to the control (2.9%) ($p < .05$, Table 2). These results intuitively illustrate that CF substitution up to 20% at least partially interrupted the continuity of noodle structure and reduced the cooking quality of noodle samples.

Effect of TGase treatment: The noodle surface of either raw or cooked noodles was apparently improved by TGase treatments, especially as shown in the cooked noodles. The starch granules in raw noodle surface were well embedded and wrapped by a continuously aggregated matrix (Figure 2G and 2I), while a smooth surface without voids and hollows were obtained after cooking (Figure 2H and 2J). The results suggest that TGase treatment optimized the protein-coating integrity and resulted in
Figure 2. Scanning electron microscopy images of noodle samples. Left panel: raw noodles; Right panel: cooked noodles. From top to bottom: WF (A and B), WF+10%CF (C and D), WF+20%CF (E and F), WF+10%CF+0.4%TGase (G and H), and WF+20%CF+0.8%TGase (I and J). Abbreviations: WF, wheat flour; CF, chickpea flour; and TGase, transglutaminase.
A better matrix of network continuity for wrapping starch granules, which was also supported by the reduced cooking loss (Table 2).

**Pasting property of noodle samples**

The effects of CF supplementation and TGase treatment on the pasting behaviors of dried raw noodles were evaluated by RVA and the results are presented in Table 2.

Effect of CF supplementation: As shown in Table 2, the addition of 10% CF had no significant influence on those RVA parameters compared to the control \([p > .05]\). Similar results of 7% CF-supplemented wheat flour blend were reported by.\(^{40}\) However, all RVA parameters were significantly lower than that of the control when the addition level increased to 20\% \([p < .001]\). This result was in agreement with a recent report\(^{15}\) and was attributed to the diluted starch content by CF addition and also higher lipid content in CF than wheat flour as mentioned above (Table 1).\(^{41}\) Stated that lipids actively inhibit swelling, which results in lower pasting viscosities. Combining the evidence from Mixolab, dynamic viscosity, and RVA, apparently a threshold value of CF supplementation existed in a range from 10\% to 20\%, which differentiated the drastic changes not only in protein network properties but also the starch pasting behavior.

Effect of TGase treatment: TGase treatment at an increasing dosage of up to 0.8\% showed an increasing trend in peak and trough viscosities, decreasing in the setback and no significant changes in the breakdown and final viscosity in most cases, except that all pasting viscosities treated by 1.2\% TGase significantly decreased \((p < .05)\). The results are consistent to C\(_3\) and setback values measured by MixoLab and the same result interpretation would apply here.\(^{37}\) Indicated that the presence of the appropriate amount of TGase could enhance entrapment of starch granules by newly formed cross-linked networks, and thus deter the rupture of swelled starch granules and increase the peak viscosity. Furthermore, the enhanced entrapment of starch granules would interfere with amylose leaking and amylose re-association during the cooling period and thus decrease setback of TGase-treated samples [Table 2]. However, the excessive crosslinking induced by 1.2\% TGase might inhibit the swelling of starch granules in the system and eventually decrease pasting viscosities (Table 2).

RVA pasting properties provide insights into the viscosity changes of starch-based suspension upon heating and cooling, which are informative in predicting cooked noodle quality.\(^{42}\) The viscosity

---

![Figure 3. SDS-PAGE of cooked noodles. Left lane: standard marker. CF addition level (%) and TGase dosage (%) are indicated at bottom for Lane # 1–12. Lane #1, #4, #7 and #10 are wheat flour control (0% CF); and Lane #10, #11 and #12 are TGase treatment control (0% TGase). The results indicated that chickpea proteins were involved in the cross-linked network catalyzed by TGase.](image-url)
Table 3. Noodle color, noodle cooking quality, and sensorial properties of flour blends of wheat flour (WF) and chickpea flour (CF) treated by transglutaminase (TGase).

| Flour blend     | WF (control) | WF+10% CF | WF+20% CF |
|-----------------|--------------|-----------|-----------|
|                 | 0            | 0.4       | 0.8       | 1.2       |
|                 | 0            | 0.4       | 0.8       | 1.2       |
| TGase (%)       | 0            | 0.4       | 0.8       | 1.2       |
|                 | 0            | 0.4       | 0.8       | 1.2       |
| Noodle color    |              | ±         | ±         | ±         |
| L*              | 80.5 ± 0.3a  | 71.6** ± 1.0b | 70.9 ± 0.7b*** | 71.6 ± 0.4b** | 71.9 ± 0.8b** | 69.7 ± 0.36 c*** | 69.66 ± 0.5 c*** | 69.66 ± 0.4 c*** | 69.66 ± 0.7 c*** |
| a*              | 0.3 ± 0.0a   | 0.8 ± 0.1b*** | 0.8 ± 0.1b*** | 0.7 ± 0.1b*** | 0.8 ± 0.0b*** | 1.0 ± 0.1b*** | 0.96 ± 0.1b*** | 0.90 ± 0.1b*** | 0.88 ± 0.1b*** |
| b*              | 9.9 ± 0.1a   | 13.1 ± 0.2b** | 13.0 ± 0.1b** | 12.9 ± 0.3b** | 12.9 ± 0.2b** | 12.0 ± 0.1b** | 12.5 ± 0.3b** | 11.9 ± 0.1b** | 12.6 ± 0.2b** |
| Cooking and sensory quality | | | | | | | | | |
| Cooking loss (%)| 2.9 ± 0.2    | 6.1 ± 0.3 a | 3.7 ± 0.2 b | 4.2 ± 0.3 b | 5.7 ± 0.3 a | 11.3 ± 0.2 a*** | 9.1 ± 0.4 b*** | 6.1 ± 0.2 d*** | 8.1 ± 0.3 c*** |
| Chewiness       | 7 ± 0        | 6.0 ± 0.4 b | 6.7 ± 0.3 a | 6.7 ± 0.2 ab | 6 ± 0.2 b | 3.5 ± 0.2 b*** | 4.9 ± 0.2 a*** | 5.3 ± 0.2 a*** | 5 ± 0.2 a**   |
| Springiness     | 7 ± 0        | 5.8 ± 0.3 b | 6.9 ± 0.3 a | 6.8 ± 0.2 a | 6 ± 0.2 b | 4.2 ± 0.3 b** | 5.3 ± 0.3 a** | 5.9 ± 0.3 a*  | 5.8 ± 0.3 a   |
| Mouthfeel       | 7 ± 0        | 6.5 ± 0.3 b | 7.8 ± 0.2 a | 6.8 ± 0.2 a | 6.5 ± 0.2 b | 3.2 ± 0.3 c*** | 4.1 ± 0.3 b*** | 5.2 ± 0.3 a*** | 5.2 ± 0.2 a** |
| Integrity       | 7 ± 0        | 6.3 ± 0.2 ab | 6.9 ± 0.2 a | 6.7 ± 0.2 a | 6 ± 0.2 b | 4.7 ± 0.2 b*** | 5.5 ± 0.2 a*** | 5.9 ± 0.2 a*  | 5.7 ± 0.2 a   |
| Total score     | 7 ± 0        | 6.0 ± 0.3 c | 7.1 ± 0.2 b | 6.3 ± 0.2 c | 5.1 ± 0.2 b | 6.3 ± 0.2 a** | 6.5 ± 0.2 a**  | 6.5 ± 0.2 a** | 6.3 ± 0.3 a   |

Values are presented as the mean ± SD, n = 3. Values within a row at the same addition level of chickpea flour followed by a different lower-case letter are significantly different by ANOVA followed a Tukey’s test (p<0.05); At a same TGase level, * (p<0.05), ** (p<0.01), or *** (p<0.001) indicates significantly different between “WF+10%CF” and “WF+20%CF” by t-test; a*, redness – greenness; b*, yellowness – blueness; L*, lightness.
Table 4. The quantification of some main protein subunits of SDS-PAGE electrophoretograms.

|        | Lane #10 |        | Lane #1 |        | Lane #4 |        | Lane #7 |        | Lane #11 |        | Lane #2 |        |
|--------|----------|--------|---------|--------|---------|--------|---------|--------|----------|--------|---------|--------|
| Band   | Relative quantification | Band   | Relative quantification | Band   | Relative quantification | Band   | Relative quantification | Band   | Relative quantification | Band   | Relative quantification |
| 1      | 0.17     | 1      | 0.14    | 1      | 0.27    | 1      | 0.26    | 1      | 0.24     | 1      | 0.28    |
| 2      | 0.43     | 2      | 0.23    | 2      | 0.23    | 2      | 0.03    | 2      | 0.23     | 2      | 0.25    |
| 3      | 0.54     | 3      | 0.11    | 3      | 0.37    | 3      | 0.02    | 3      | 0.13     | 3      | 0.22    |
| 4      | 1.14     | 4      | 0.87    | 4      | 0.00    | 4      | 0.40    | 4      | 0.19     | 4      | 0.81    |
|        |          |        |         |        | 5       | 0.76   | 5       | 0.06   | 5       | 0.63   |
|        |          |        |         |        | 6       |        |         |        |          |
| Lane #5| Band     | Relative quantification | Band   | Relative quantification | Band   | Relative quantification | Band   | Relative quantification | Band   | Relative quantification |
| 1      | 0.32     | 1      | 0.15    | 1      | 0.26    | 1      | 0.47    | 1      | 0.06     | 1      | 0.84    |
| 2      | 0.33     | 2      | 0.20    | 2      | 0.25    | 2      | 0.39    | 2      | 0.37     | 2      | 0.14    |
| 3      | 0.33     | 3      | 0.22    | 3      | 0.19    | 3      | 0.52    | 3      | 0.31     | 3      | 0.12    |
| 4      | 0.58     | 4      | 0.31    | 4      | 0.24    | 4      | 0.28    | 4      | 0.13     | 4      |        |
parameters are related to various qualities of Asian noodles. For example, higher peak viscosity and final viscosity usually contribute to a smooth surface and elastic mouth feel of cooked noodles. Based on the RVA results, improved cooking and sensory quality of noodles made from CF-supplemented flour treated by 0.4–0.8% TGase would be expected and will be discussed later.

**Protein electrophoretic pattern of noodle samples**

The SDS-PAGE electrophoretograms of proteins extracted from the cooked noodles made from WF control flour and CF-supplemented flour blends followed by TGase treatments are shown in Figure 3, and the relative quantification of some main protein subunits is presented in Table 4. As expected, the addition of CF significantly enriched the protein variety of CF-supplemented noodle samples (Lane #11 and #12 for 10% CF, and 20% CF, respectively) compared with the WF control noodle (Lane #10), especially the bands 1, 2, 3, and 4, which were chickpea albumin and globulin. Even for WF control (Lane #10), TGase treatment of WF noodles significantly decreased the amount of proteins below 20 kDa but specifically intensified a few bands above 31 kDa (Lane #10, #1, #4, and #7), which is consistent to a previous report by. The intensive protein cross-linking was observed in all the CF-supplemented samples, especially in the 20% CF-added samples (Lane #3, #6, and #9). TGase treatment largely changed the banding distribution and increased the intensities of polypeptide bands above 66.2kDa, and the band intensities and molecular weights were greatly increased with an increasing CF addition level from 10% to 20% at any given TGase dosage (Figure 3 and Table 4). Apparently, CF proteins were involved in cross-linking by TGase, especially elaborated by the intensified protein bands above 66.2 kDa (Figure 3). These results provide direct evidence to support the results from Mixolab, dynamic viscosity, and RVA. Furthermore, a significant amount of large molecular weight proteins was intercepted at the top of SDS-PAGE separation gel in samples treated with 1.2% of the TGase (band 1 of Lane #9). Similar observations have been reported that protein cross-linked by TGase formed large complexes which were unable to enter the SDS-PAGE separation gel. As a summary, our results clearly demonstrated that CF proteins are involved in the crosslinking catalyzed by TGase which significantly strengthened the protein matrix.

**Color, cooking and sensory quality of noodles**

Effect of CF supplementation: As shown in Table 3, CF addition significantly decreased the lightness as well as increased the redness and yellowness of noodle samples compared with pure wheat noodles. Cooking loss of the control noodle was 2.9%, which increased to 6.1% by 10% CF substitution and drastically increased to 11.3% by 20% CF substitution. Similar results were reported by others and have been attributed to the dilution effects on gluten-forming proteins and causing the weakening of the dough. Insufficient gluten proteins limited the formation of continuous gluten network which was incapable of wrapping starch granules within the noodle matrix as shown in Figure 2D and 2F. Secondly, the higher amount of fibre in CF possibly interrupted the continuous gluten network and protein-starch matrix of the noodles. Both factors would cause an increase in cooking loss of noodles.

Effect of TGase treatment: Nonetheless, TGase had no significant influence on each kind of noodle samples compared with their counterpart. Treatment at a dosage ≤0.8% effectively decreased the cooking loss of CF-added noodles (p< .05). However, there was no further effectiveness when the dosage was up to 1.2%. An optimal range of TGase dosage (i.e., 0.4–0.8%) seems to effectively cross-link proteins in a well-controlled manner and forms a continuous protein network with balanced rigidity and elasticity, which might not only maximally wrap the starch granules during dough sheeting process but also adapt to the starch granule swelling and be resistant to rupturing during noodle cooking, and hence lower the cooking loss (Table 3). In contrast, over-dosed TGase treatment
could cause excessive cross-linking and lead to stiff but fragile protein network, [50] which possibly ruptures during cooking and results in higher cooking loss as shown in Table 3.

Cooking loss can serve as an indicator of the structural integrity of the noodle network and thus noodle quality. [51,52] Generally, cooking loss of noodles should not exceed 8% of the dry weight. [52] As shown in Table 3, a significant increase in cooking loss while decrease in sensory scores was induced by CF supplementation, but TGase treatment resulted in significant improvements in sensory parameters (p < .05). Noodle samples containing 10% CF followed by 0.4% TGase treatment had the highest sensory scores among all samples (p < .05), and the sensory score of noodle samples containing 20% CF and treated by 0.8% TGase was comparable to the control (p > .05). These results indicate that CF addition and TGase treatment are feasible to synergistically enhance nutritional values and dough properties of Asian noodles without any negative effects on sensory properties of resultant noodles.

**Pearson correlation**

Pearson correlation coefficients among element components, mixing behavior, dynamic viscoelasticity, pasting property, cooking, and sensory qualities of WF control, WF/CF flour blends, dough, and raw/cooked noodle samples are presented in Supplemental Table 1. Element components (e.g., protein, ash, lipid, carbohydrate, and total fibre content) were highly significantly correlated with each other (p < .001). Interestingly, element components were also significantly correlated with Mixolab parameter C2 (p < .01, except P < .05 with total fibre), development time (p < .001), and setback (p < .01, except p < .05 with total fibre), but not significantly correlated with other variables such as water absorption, C3, and stability, dough dynamic viscoelasticity, all the RVA pasting properties of raw noodle powder, cooking loss and sensory properties of cooked noodles (p > .05). Probably, the strong effect of TGase treatments on dough structure overrides the influence of the chemical components and dominates the variances of this set of samples. As a result, almost all the variables related to a structure obtained by large deformation measurements (i.e., mixing blades of MixoLab, the propeller of RVA, and teeth-biting in sensory evaluation) and cooking loss were highly significantly correlated [p < .001 in most case], which signifies the strong effects of strengthened protein network cross-linked by TGase treatment. Development time and setback measured by MixoLab did not involve in those correlations, possibly these two variables related to more on chemical component rather than TGase treatment. Surprisingly, there was a lack of correlation between setback_MixoLab and setback_RVA. Chopin Applications, [26] indicated that MixoLab produces results based on measurements on the dough, whereas RVA was based on a suspension which might explain the reason. Among all those variables, complex dynamic viscoelasticity parameters log a* significantly correlated with RVA setback [p < .05] and total score of cooked noodles (p < .05), while b* significantly correlated with springiness (p < .05) and total score (p < .001).

**CONCLUSION**

CF supplementation to WF diluted both gluten-forming protein and total starch content of the flour blend, resulting in the weak dough, high cooking loss, and poor sensory quality. TGase treatment at dosages of 0.4%-0.8% effectively amended the above negative effects. The cooked noodles supplemented with 10% CF and 0.4% TGase treatment had the lowest cooking loss and comparable sensory qualities to WF noodle control. SDS-Page electrophoresis and dynamic viscoelasticity indicated that CF proteins were involved in the crossing-linking, catalyzed by TGase. In summary, CF-supplementation followed by TGase treatment at appropriate proportions could synergistically boost the nutritional value and texture properties of Asian noodles.
Acknowledgments

This research was partly supported financially by the key research project of Northern Minzu University (2019KJ20) and the funding of the Collaborative Innovation Center for Food Production and Safety of North Minzu University. We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

Funding

This work was supported by the key research project of North Minzu University [2019KJ20]

ORCID

Lihong Han [http://orcid.org/0000-0002-4462-753X]

References

[1] Hou, G.; Asian Noodles: Science, Technology, and Processing; Wiley: Hoboken, New Jersey, 2010.
[2] Lu, Z.-H.; Seetharaman, K. Suitability of Ontario-grown Hard and Soft Wheat Flour Blends for Noodle Making. Cereal Chem. 2014, 91(5), 482–488. DOI: 10.1094/CHEM-10-13-0218-R.
[3] Rathod, R. P.; Annapure, U. S. J. L. Physicochemical Properties, Protein and Starch Digestibility of Lentil Based Noodle Prepared by Using Extrusion Processing. LWT Food Sci. Technol. 2017, 80, 121–130. DOI: 10.1016/j.lwt.2017.02.001.
[4] Aydin, E.; Gocmen, D. Cooking Quality and Sensorial Properties of Noodle Supplemented with Oat Flour. Food Sci. Biotechnol. 2011, 20(2), 507–511. DOI: 10.1007/s10068-011-0070-1.
[5] Reungmaneepaitoon, S.; Sikkhamondhol, C.; Tiangpook, C. Nutritive Improvement of Instant Fried Noodles with Oat Bran. Songklanakarin J. Sci. Technol. 2006, 28(Suppl.1), 89–97.
[6] Kruger, J. E.; Hatcher, D. W.; Anderson, M. I. The Effect of Incorporation of Rye Flour on the Quality of Oriental Noodles. Food Res. Int. 1998, 31(1), 27–35. DOI: 10.1016/s0963-9969(98)00055-6.
[7] Bhise, S.; Kaur, A.; Aggarwal, P. Development of Protein Enriched Noodles Using Texturized Defatted Meal from Sunflower, Flaxseed and Soybean. J. Food Sci. Technol. 2015, 52(9), 5882–5889. DOI: 10.1007/s13197-014-1630-1.
[8] Iwami, K.; Yasumoto, K. Amine-binding Capacities of Food Proteins in Transglutaminase Reaction and Digestibility of Wheat Gliadin with c-attached Lysine. J. Sci. Food Agric. 1986, 37(5), 495–503. DOI: 10.1002/jfsa.2740370511.
[9] Azubuike, C. U. J. A. E. J.; Process Variables Combination of Roasted African Breadfruit Seed Flour and the Essential Amino Acid Needs of Infants and Children. Agric. Extens. J. 2019, 3(3), 121–128.
[10] Singh, N.; Pulses: An Overview. J. Food Sci. Technol. 2017, 54(4), 853–857. DOI: 10.1007/s13197-017-2537-4.
[11] Meng, X.; Threinen, D.; Hansen, M.; Driedger, D. Effects of Extrusion Conditions on System Parameters and Physical Properties of a Chickpea Flour-based Snack. Food Res. Int. 2010, 43(2), 650–658. DOI: 10.1016/j.foodres.2009.07.016.
[12] Paredes-López, O.; Ordorica-Falomir, C.; Olivares-Vázquez, M. R. Chickpea Protein Isolates: Physicochemical, Functional and Nutritional Characterization. J. Food Sci. 1991, 56(3), 726–729. DOI: 10.1111/j.1365-2621.1991.tb05367.x.
[13] Mokni, G. A.; Sila, A.; Maklouf, G. I.; Blecker, C.; Danthine, S.; Attia, H.; Besbes, S.; Besbes, S. Structural, Functional and ACE Inhibitory Properties of Water-soluble Polysaccharides from Chickpea Flours. Int. J. Biol. Macromol. 2015, 75, 276–282. DOI: 10.1016/j.ijbiomac.2015.01.037.
[14] Li, P.; Shi, X.; Wei, Y.; Qin, L.; Sun, W.; Xu, G.; ... Liu, T. Synthesis and Biological Activity of Isoflavone Derivatives from Chickpea as Potent Anti-diabetic Agents. Molecules. 2015, 20(9), 17016–17040. DOI: 10.3390/molecules200917016.
[15] Jia, F.; Ma, Z.; Wang, X.; Li, X.; Liu, L.; Hu, X. Effect of Kansui Addition on Dough Rheology and Quality Characteristics of Chickpea-wheat Composite Flour-based Noodles and the Underlying Mechanism. Food Chem. 2019, 298, 125081. DOI: 10.1016/j.foodchem.2019.125081.
[16] Djoullah, A.; Djemouine, Y.; Hussin, F.; Saurel, R. Native-state Pea Albumin and Globulin Behavior upon Transglutaminase Treatment. Process Biochem. 2015, 50(8), 1284–1292. DOI: 10.1016/j.procbio.2015.04.021.
[17] Bellido, G. G.; Hatcher, D. W. Effects of a Cross-linking Enzyme on the Protein Composition, Mechanical Properties, and Microstructure of Chinese-style Noodles. Food Chem. 2011, 125(3), 813–822. DOI: 10.1016/j.foodchem.2010.08.008.
[41] Tester, R. F.; Morrison, W. R. Swelling and Gelatinization of Cereal Starches. 1. Effects of Amylopectin, Amylose, and Lipids. *Cereal Chem.* 1990, 67(6), 551–557.

[42] Fan, H.; Ai, Z.; Chen, Y.; Fu, F.; Bian, K. Effect of Alkaline Salts on the Quality Characteristics of Yellow Alkaline Noodles. *J. Cereal Sci.* 2018, 84, 159–167. DOI: 10.1016/j.jcs.2018.10.007.

[43] Li, M.; Sun, Q.-J.; Han, C.-W.; Chen, -H.-H.; Tang, W.-T. Comparative Study of the Quality Characteristics of Fresh Noodles with Regular Salt and Alkali and the Underlying Mechanisms. *Food Chem.* 2018, 246, 335–342. DOI: 10.1016/j.foodchem.2017.11.020.

[44] Bhattacharya, M.; Zee, S. Y.; Corke, H. Physicochemical Properties Related to Quality of Rice Noodles. *Cereal Chem.* 1999, 76(6), 861–867. DOI: 10.1094/CCHEM.1999.76.6.861.

[45] Crosbie, G. B.; The Relationship between Starch Swelling Properties, Paste Viscosity and Boiled Noodle Quality in Wheat Flours. *J. Cereal Sci.* 1991, 13(2), 145–150. DOI: 10.1016/S0733-5210(09)80031-3.

[46] Li, M.; Luo, L.-J.; Zhu, K.-X.; Guo, X.-N.; Peng, W.; Zhou, H.-M. Effect of Vacuum Mixing on the Quality Characteristics of Fresh Noodles. *J. Food Eng.* 2012, 110(4), 525–531. DOI: 10.1016/j.jfoodeng.2012.01.007.

[47] Chang, Y.; Alli, I.; Konishi, Y.; Ziomek, E. Characterization of Protein Fractions from Chickpea (*Cicer Arietinum* L.) And Oat (*Avena Sativa* L.) Seeds Using Proteomic Techniques. *Food Res. Int.* 2011, 44(9), 3094–3104. DOI: 10.1016/j.foodres.2011.08.001.

[48] Zhao, Y. H.; Manthey, F. A.; Chang, S. K. C.; Hou, H.-J.; Yuan, S. H. Quality Characteristics of Spaghetti as Affected by Green and Yellow Pea, Lentil, and Chickpea Flours. *J. Food Sci.* 2006, 70(6), S371–S376. DOI: 10.1111/j.1365-2621.2005.tb11458.x.

[49] Kumar, S. B.; Prabhasankar, P. A Study on Starch Profile of Rajma Bean (*Phaseolus Vulgaris*) Incorporated Noodle Dough and Its Functional Characteristics. *Food Chem.* 2015, 180, 124–132. DOI: 10.1016/j.foodchem.2015.02.030.

[50] Gerrard, J.; Fayle, S.; Brown, P.; Sutton, K.; Simmons, L.; Rasiah, I. J. J. O. F. S. Effects of Microbial Transglutaminase on the Wheat Proteins of Bread and Croissant Dough. *J. Food Sci.* 2001, 66(6), 782–786. DOI: 10.1111/j.1365-2621.2001.tb15172.x.

[51] Zhou, Y.; Cao, H.; Hou, M.; Nirasawa, S.; Tatsumi, E.; Foster, T. J.; Cheng, Y. Effect of Konjac Glucomannan on Physical and Sensory Properties of Noodles Made from Low-protein Wheat Flour. *Food Res. Int.* 2013, 51(2), 879–885. DOI: 10.1016/j.foodres.2013.02.002.

[52] Wu, Y. V.; Youngs, V. L.; Warner, K.; Bookwalter, G. N. Evaluation of Spaghetti Supplemented with Corn Distillers’ Dried Grains. *Cereal Chem.* 1987, 64(6), 434–436.