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Chapter

Innovative Application of Soy Protein Isolate and Combined Crosslinking Technologies to Enhance the Structure of Gluten-Free Rice Noodles

Moses Ojukwu and Azhar Mat Easa

Abstract

Soy protein isolate (SPI) may serve as a health-enhancing functional ingredient in many food products due to the content of isoflavones. However, the high protein content may also be exploited as a structure modifier in gluten-free noodles. We applied Soy protein isolate to improve rice flour noodles’ structure, textural, and cooking properties by combining cross-linking and cold gelation of soy protein isolate using microbial transglutaminase and glucono-δ-lactone, respectively. The simultaneous cross-linking yielded noodles with improved structure and textural properties, mainly due to a more robust microstructure resulting from an increase in intermolecular protein cross-linking promoted by microbial transglutaminase and glucono-δ-lactone. However, the structurally enhanced noodles showed longer cooking time and reduced cooking yield upon drying. This was solved by employing pre-drying steaming treatments for 5 or 10 min to yield noodles with shorter cooking times, lower cooking losses, and improved cooking yield. We have also developed an alternative process technology using superheated steam (SHS) technology. The superheated steam technology made it possible to open up the structurally enhanced air-dried noodles by promoting faster gelatinization, as evidenced by reduced enthalpy, increased cooking yield, and sustained crystallinity of the starch granules noodle matrix.

Keywords: soy protein isolates, noodles, texture, cross-linking, cooking properties

1. Introduction

Soy protein contains all essential amino acids, and its consumption has been beneficial to human physiological needs as it lowers cholesterol and reduces the risk of coronary heart and cardiovascular diseases [1, 2]. Soy protein has been used in food systems for its excellent gelling, water-holding capacity, sensory and functional properties [3]. Soybeans have been an excellent source of proteins in Asia and are consumed in various forms, such as soymilk, soy curd (tofu), and fermented soy paste (miso).
Soy protein isolates (SPI) are produced by removing the oil content of soy proteins. When the pH of aqueous soy proteins is reduced to pH 4.5–4.8, they are separated into whey fractions and storage globulins. SPI comprises different proteins, and the essential components are grouped into 2S, 7S, 11S, and 15S, representing their sedimentation coefficients when subjected to a centrifugal field, with the β-conglycinin (7S) and glycinin (11S) being the majority. While the former lacks disulfide bonds, glycine has a more compact structure equilibrated by disulfide bonds and thus possesses lower gelling, emulsifying, and foaming capacity when compared with β-conglycinin [1]. Because of this, SPI has been used to affect the textural and structural properties of noodles [2].

The consumer acceptability of noodles is dependent on the overall texture of rice noodles [3]. The texture of noodles is simply the surface mouthfeel and the resistance to chewing and the textural properties of noodles are influenced by various factors, such as the properties of the type of flour, such as amylose/amylopectin ratio of starch, the protein, and lipid composition, the processing conditions, and the thermal properties of the flour [4].

The Texture Profile Analyzer (TPA) proposed by Szczesniak [5] can be used to measure the textural properties of solid food materials, including rice noodles [6]. The TPA method is a 2-time compression type test from which parameters, such as hardness, chewiness, adhesiveness, cohesiveness, fracturability, springiness, gumminess, chewiness, of the noodles can be obtained [7]. It is the most straightforward and frequent technique to relate instrumental measurement with sensory evaluation.

Hardness is the force required to cause a pre-determined deformation. It also measures the resistance of noodles to compressions which is the maximum force of the first compression [6]. The amount of energy required to break down the noodles while chewing before swallowing is expressed in chewiness. Cohesiveness demonstrates how well the noodles withstand the second deformation and influence chewiness by indicating the extent of the structure breakdown throughout chewiness [7]. While the degree of adherence of the noodle on the probe after the first compression is the adhesiveness of the noodle [5], the noodles’ ability to return to their original shape after compression is called the noodle’s springiness.

In noodles’ research, cooking parameters indicate the impact of the noodles’ structure on sustainability [8]. The cooking quality of noodles can be evaluated by measuring the length of cooking time, the cooking loss, and the cooking yield. The cooking quality of noodles is critical to noodles’ sensory and textural properties [8]. Starch gelatinization, protein coagulation, and other structural changes occur in proteins during cooking. These account for how long it takes to get the noodles properly cooked, their water retention capacity, and their ability to withstand the cooking processes and maintain their structure.

Consumers show a preference for noodles with short cooking time, less cooking loss, and high cooking yield [8, 9]. Noodles are usually cooked in boiling water. The optimum cooking time is the time it takes for the white core in the center of a noodle strand to disappear [10]. Rice noodles cook faster than wheat-based noodles. This is because the primary raw material for rice noodles, rice flour, does not contain gluten. Robust protein networks by gluten limit water ingress into the noodles, thus elongating the starch gelatinization, a precursor for the noodles to be cooked [8, 11]. The cooking time of rice noodles is influenced by the rice starch properties and other additives, such as hydrocolloids and starches. Rice noodles prepared by blending rice flour with other starches have a longer cooking time due to alteration in the starch’s gelatinization temperatures, which ultimately expanded the water retention capacity of the noodles [12].
The cooking loss of rice noodles shows the number of substances lost from the noodles during cooking. It is indicative of the structural integrity of the noodles. Rice noodles with high cooking loss are undesirable because they become sticky due to increased leaching of amylose and starch recrystallization. According to the Chinese standard for starch-based noodles, noodles with a maximum of 10% cooking loss are acceptable [13, 14]. Rice noodles prepared from rice flour with high amylose content have less cooking loss. Also, the inclusion of protein isolates and protein cross-linking impart some form of structural integrity on the noodles, minimizing the cooking loss [15].

Cooking yield can be used to estimate the water retention capacity of the noodles. During cooking, noodles absorbed water and increased weight [9, 16]. The differences in the cooking yield of rice noodles with noodles made from wheat and other flours are due to differences in amylose concentrations, swelling power, and the pasting properties of starches from different sources [12].

2. Gelation of soy proteins

The ability of SPI to form gel is an essential functional property for its use in noodle structure modification [17, 18]. Soy proteins are susceptible to denaturation when thermally treated. Heat exposes the hydrophobic groups in proteins, increasing hydrophobicity, decreasing net charges, thus promoting protein networks [19]. In the heat-induced process, aggregation, network formation, and the unfolding of the hydrophobic parts are interwoven (Figure 1). Cold gelation could be achieved by introducing an acidulant such as glucono-δ-lactone that releases gluconic acid slowly into the system to promote gelation of thermally aggregated protein molecules. The gelation and coagulation of SPI have involved hydrophobic and covalent cross-links [20]. SPI gels can be enhanced using microbial transglutaminase (MTG), which is a well-known food-grade enzyme that utilizes the acyltransferase process to join the γ-carboxamide (acyl donor) of a glutamine residue to the γ-amine (acyl acceptor) of lysine residues along protein chains. The cross-linking action of MTG on SPI in noodles has been shown by Ojukwu et al. [18]. Upon examination using sodium
dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE), it was evident that protein networks formed after incubating for 30 min.

3. Innovating functional (health-enhancing) noodles

In the beginning, we have innovated health-enhancing noodles by employing banana peel or banana pulp flours [21]. It was quite possible to use banana peel flour to replace that of wheat partially. Banana peels which make up almost 40% of the fruit can control starch hydrolysis in noodles. In this study, cooked noodles made from Cavendish banana peel flour were characterized for physicochemical properties, including elasticity, pH, tensile strength, and color. Banana peel noodles exhibited higher elasticity and lower glycemic index than the control (wheat noodles), while the tensile strength was similar. The addition of banana pulp or banana peel to the formulation lowers the predicted glycemic index of the cooked noodles. The effect is more evident in the banana peel formulation because of its higher dietary fiber and resistant starch contents. Overall, the substitution of banana peel or banana pulp can alter the physicochemical properties of the cooked noodles [22].

Yellow alkaline noodles prepared with green banana pulp flour effectively control starch hydrolysis, which can lower the ingestion rate and absorption of carbohydrates in noodles [21]. The green banana pulp can also be used as an effective flour substitute. Despite the potential of the banana peel or banana pulp flours as functional ingredients in noodles, partial substitution of the wheat flour at higher levels was not successful due to lack of protein network to impart structure and texture. We then sought plant protein isolates that could be cross-linked at relatively low application levels to enhance the noodles’ network. Consequently, it would also impart good cooking, handling, and eating quality. We evaluated soy protein isolate and achieved various functionalities to improve the quality characteristics of the noodles.

3.1 Structural modification of wheat flour noodles using SPI

Noodles are structurally altered for various purposes, such as to make them able to withstand processing and cooking and release glucose more slowly during digestion. Alteration of structure in canned noodles can lower the cooking loss during the retort process. For instance, it was shown that cross-linking agents, such as MTG and ribose could prevent damage to canned SPI-yellow alkaline noodles’ during thermal processing [2]. Thus, partially substituted yellow alkaline noodles treated with MTG and ribose separately and in combination generated an enhanced structure that can withstand thermal processing.

3.2 Use of SPI in coating yellow alkaline noodles

Capsaicin is an antiobesity agent and an active component of chili powder. However, chili can cause pain, therefore attempts to affect the release of chili in the mouth were also tried using cross-linking agents, SPI, and layering technology.

For the capsaicin to be effectively delivered, the compound should enter the body in a considerable quantity. However, a higher dose can cause a burning sensation in the mouth. Noodles, one of the widely eaten products, can be used for safe delivery
inside the body. It is suggested that chili powder can be added to noodles by sandwiching the dough between layers of wheat dough. The addition of resistant starch flour or SPI and microbial transglutaminase to the sandwich layers can lower the glycemic index [23]. The capsaicin retaining ability of noodles formulated with SPI at the core was higher than that prepared using resistant starch flour. MTG was used to enhance the elasticity, while SPI was used as a texture enhancer. A combination of MTG and SPI had increased the network structure of “sandwiched noodles” that aids in capsaicin retention. Compared to other formulations, layered noodles prepared with 1.5 g MTG and 5 g SPI per 100 g mixture exhibited the best capsaicin retention and tensile parameters [24].

4. Enhancing the textural, structural, and cooking properties of fresh rice noodles using SPI and combined cross-linking technologies

Glucono-δ-lactone (GDL) is a cyclic ester. It contains a lactone group and gradually dissolves in water to form gluconic acid, causing a reduction in pH in food systems (Figure 2). It is widely used as an acidulant in yogurts, sausages, and different dessert mixes. GDL is used as a coagulant in the production of tofu, a soymilk curd [25, 26]. The introduction of GDL into protein alters the pH toward the isoelectric point and subsequently gels the proteins through electrostatic repulsion, salt-bridging, and noncovalent interactions, such as hydrogen bonding and van der Waals forces [27, 28]. The aggregation of protein in GDL-induced acidification of soymilk proteins occurred at pH 5.9 [29].

The combined control of the acidification and gelling of proteins by heat treatment creates a “cold gelation” [20, 30]. In the cold gelation process, aggregates and the formation of a protein network are separated in time. Cold gelation is made of two steps. First, at neutral pH well above the isoelectric point, low concentrations of native globular proteins are thermally treated, causing the native proteins to unfold and form disulfide cross-linked aggregates. The soluble aggregates formed were made possible due to net surface charge proteins and repulsive forces, which prevent random aggregation. Depending on the denaturation conditions, a stable dispersion of aggregates is obtained after cooling to room temperature. Secondly, an alteration in the quality of the solvent causes gelation. Typically, cold-set gels by acidification are stronger than salt-induced cold-set gels for the same protein concentration [31].

Figure 2. Hydrolysis of GDL.
SPI and MTG have been used to improve noodles’ texture and mechanical properties, but a mixture of SPI, MTG, and GDL has never been tested to improve the texture and other properties in rice noodles. Rice flour-SPI noodles containing MTG and GDL were tested for various parameters to develop a gluten-free alternative to wheat flour noodles with comparable or better characteristics. Rice noodles were prepared to contain 5% SPI, were cross-linked with MTG (1% w/w rice flour), and cold-gelled using GDL (1% w/w rice flour). This restructured fresh rice noodle termed RNS-COM (SPI-rice noodle formed via combined cross-linking technology) showed heavier protein bands than a typical rice protein band, indicating the polymerization of proteins into bigger matrices. The cooking time for RNS-COM was significantly lower than commercially available yellow alkaline noodles (YAN). No significant difference was found between the percentage cooking loss between the two. RNS-COM had better textural parameters, including hardness and chewiness, while compactness and tensile strength were comparable (Figure 3). Overall, the RNS-COM noodles performed better than regular rice noodles and can potentially be used in place of YAN [18]. The addition of SPI in rice noodles made them have better textural properties than the control (RN). Increased SPI cross-linking by MTG and GDL in RNS-COM gave a compact and robust protein matrix embedded with the starch granules within the rice noodles (data not shown).

SPI, MTG, and GDL are additives commonly used in the food industry to enhance foods’ texture and physiochemical properties. Adding these additives to rice noodles makes them more palatable and may mimic those of wheat flour noodles, such as YAN. It is crucial to optimize the values of such additives to make the product marketable. Optimization is required for factors, including hardness, springiness, chewiness, tensile strength, and cooking time. It is suggested that an addition of SPI, 68.32 (g/kg of rice flour), MTG, 5.06 g/kg of rice flour), and GDL, 5.0 (g/kg of rice flour) improved the various parameters. The hardness of the final product with optimized values of SPI, MTG, and GDL was hardness (53.19 N), springiness (0.76), chewiness (20.28 J), tensile strength (60.35 kPa), and cooking time (5.15 min) [32].

![Figure 3. Standardized textural properties of rice noodles (RN = rice noodles with 100% flour, RNS-MTG = rice noodles with 5% SPI, cross-linked with 1% MTG, RNS-GDL = rice noodles with 5% SPI, gelled with 1% GDL, RNS-COM = rice noodles with 5% SPI, cross-linked with 1% MTG and gelled with 1% GDL).](image-url)
5. Improving the textural, structural, and cooking properties of air-dried rice noodles using SPI and combined cross-linking technologies

Despite having improved texture, taste, and flavor, fresh rice noodles deteriorate after preparation and are susceptible to spoilage due to their high moisture levels. Furthermore, fresh noodles are prone to discoloration, which is unappealing [33]. As a result, reducing the moisture content will extend the shelf life of the noodles while also preserving their texture and aroma, potentially increasing their market value [34]. Because of their less porous structure, air-dried noodles have been confirmed to shrink during processing, have poor rehydration characteristics, develop a tough texture, and have long cooking times [35, 36]. This problem could be solved by carrying out a steaming process before drying.

Therefore, RNS-COM was steamed before drying to yield air-dried RNS-COM (Figure 4). Findings revealed that RNS-COM was chewier and springier than air-dried RN because of the improved swelling of starch molecules in the noodle framework. Furthermore, the protein cross-links formed by MTG and GDL reinforced covalent networks in the noodles, increasing the chewiness. The springier the noodles, the denser the cross-links between amylose and other network forming molecules in a noodle structure [37, 38]. The improved springiness of the RNS-COM could be attributed to increased polymerization prompted by the additional proteins and cross-linking agents. GDL may have prompted some cold protein gelation and better overall interactions between starch molecules, resulting in stronger and harder RNS-COM with enhanced starch retrogradation on the noodles’ surface [39].

Figure 4.
Air-dried RNS-COM (RNS-COM = rice noodles with 5% SPI, crosslinked with 1% MTG and gelled with 1% GDL)
Initially, the structurally optimized air-dried RNS-COM suffered a longer cooking time and a reduced yield; however, this was resolved by using pre-drying steaming treatments for 5 or 10 min. The subsequent air-dried RNS-COM had shorter cooking times, lower cooking losses, and higher yields. The microstructures of the steamed and dried combinedly-treated RNS-COM differed noticeably, but the relative crystalline structure of starch was preserved just after the steaming and drying treatments [40].

6. Our latest approach

Superheated steam (SHS) drying of food materials is a technological innovation with inherent benefits over hot air-drying processes, such as shorter drying rates due to higher temperatures, relatively low energy demand, little or emission of harmful pollutants in the atmosphere, and the absence of oxidation process owing to the unavailability of oxygen [41]. SHS enhanced the structurally improved dried RNS-COM (RNS-COM-SHS), cooking, and textural properties. The SHS, generated with a superheated steam oven (31L SHARP Healsio AX1700VMR) set at 120°C was able to unlock the framework of RNS-COM-SHS, leading to faster gelatinization of starch granules and a 1-minute decrease in optimum cooking time. RNS-COM-SHS had a compact structure with starch granules tightly integrated with the proteins (Figure 5). More cavities and less tight areas in RNS-COM-SHS would offer less restriction to moisture penetration into the noodle structure, lowering the cooking time and improving cooking yield.

Superheated steam processing had no adverse effects on the essential textural properties of the noodles, but it resulted in noodles that took less time to cook due to faster starch gelatinization, as evidenced by lower enthalpy. As a result, superheated steam processing of RNS improves the cooking and textural properties of dried rice-flour soy protein isolate noodles.

Figure 5.
Structural morphology of the noodles. (a) RN-SHS, (b) RNS-COM-SHS.

7. Conclusion

Fresh rice flour noodles with enhanced textural and mechanical properties were prepared by incorporating soy protein isolate, MTG, and GDL. Improvements in specific properties can be attributed to enhanced cross-linking of proteins due to MTG and GDL-induced cold gelation at reduced pH values.
Upon air-drying, the structurally enhanced RNS-COM showed longer cooking time and reduced cooking yield that could be solved by employing pre-drying steaming treatments. The robust network in air-dried RNS-COM can be opened by superheated steam, which allows for faster gelatinization, evidenced by reduced enthalpy, increased cooking yield, and sustained crystallinity of the starch granules in the noodle matrix.

Therefore, the superheated steam processing of RNS improves the cooking characteristics and textural qualities of dried rice-flour soy protein isolate noodles.

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Conflict of interest

The authors declare no conflict of interest.

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