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Influence of resistant starch, xanthan gum, inulin and defatted rice bran on the physicochemical, functional and sensory properties of low glycemic gluten-free noodles

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ABSTRACT

The study aims to evaluate the effects of xanthan gum (XG), inulin and defatted rice bran on the physicochemical, functional and sensory properties of the gluten-free noodle prepared from Pathumthani 80 rice (RD 31) native autoclaved resistant starch (NARS). The increase in concentration of XG (0.625–5%) in the formulation of gluten free noodles resulted a significant decrease ($p < 0.05$) in resistant starch content whereas, the tensile strength was increased. RD 31-NARS gluten-free noodles with 2.5% XG received the high sensory scores and further selected for the addition of inulin and defatted rice bran (5%, w/w), separately. RD 31-NARS gluten free noodle with XG (2.5%) and defatted rice bran exhibited the highest protein (4.62%), fiber (0.35%) and ash content (1.45%). Further, addition of inulin and defatted rice bran significantly ($p < 0.05$) decreased the glycemic index and increased the cooking time and firmness. The surface morphology of gluten free noodles showed relatively porous structure under the scanning electron microscope (SEM) after the addition of rice bran (5%) and inulin (5%). Thus, resistant starch along with gums and fibers can be used to develop gluten free functional foods with better acceptability.

1. Introduction

Noodles are quite popular among Asian people and consumed by large number of populations worldwide. However, gluten, the major protein of wheat flour is associated with celiac disease, gluten allergy and non-celiac gluten sensitivity, the conditions collectively termed as gluten intolerance (Balakireva & Zamyatnin, 2016). This implies the increase in demand for gluten-free food products with the increase in consumer health awareness. The consumer demand for nutraceutical products is gaining interest during the last decade (Daliu, Santini, & Novellino, 2018). Nutraceutical products are associated with prevention of various ailments and non-communicable diseases (Daliu, Santini & Novellino, 2019; Santini & Novellino, 2017). The formulation of food product which improves total dietary intake and reduce production cost can serve as comprehensive solution to malnutrition (Santini, Novellino, Armini, & Ritieni, 2013).

Due to increase in demand for gluten free products, non-wheat flours such as rice, buckwheat and chestnut flours have been used in the formulation of gluten free noodles (Giménez-Bastida, Piskuła, & Zieliński, 2015; Heo, Lee, Shim, Yoo, & Lee, 2013; Moreira, Chenlo, Torres, & Prieto, 2012). Non starch polysaccharides can be incorporated into gluten free formulations to improve the texture attributes (Cai et al., 2016). Oat fiber, XG and locust bean gum were reported to improve the textural and flavor attributes of gluten free foods (Gallagher, Gormley, & Arendt, 2004; Inglett, Peterson, Carriere, & Maneepun, 2005) Rice flour is regarded as the best replacement of wheat flour due to its bland taste, high digestibility, and the smaller starch granules that benefit the noodle textural characteristics (Chung, Cho, & Lim, 2012; Kang et al., 2017). However, rice starch is associated with the high glycemic load and other potential risks (Boers, ten Hoorn, & Mela, 2015).

The resistant starch represents fraction of starch that resists digestion in the upper digestive tract and is fermented by the probiotics in the large intestine, producing short-chain fatty acids (Nasrin & Anal, 2014). Retrograded resistant starch type 3 (RS 3) produced by repeated cycles of autoclaving and retrogradation showed a potential commercial application in the formulation of nutraceutical foods (Shrestha, Sadiq, & Anal, 2018) with physiologic effect similar to dietary fiber, assists to reduce glycemic index (Zhou, Meng, Chen, Zhu, & Yuan, 2014), postprandial blood glucose and insulin response (Raigond,

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Ezekiel, & Raigond, 2015). During autoclaving treatment, the starch granules become fully disrupted, which upon cooling form double helices stabilized by hydrogen bonds. Thus, the repeated autoclaving-cooling treatments lead to the formation of resistant starch type 3 crystallites, that are resistant to starch hydrolyzing enzymes due to their tightly packed structure (Birt et al., 2013).

The texture of noodles should be firm and elastic with smooth surface. Furthermore, hydrocolloids such as xanthan gum (XG), inulin etc. help to develop and stabilize the gluten free network by regulating the water binding capacity and increasing the intermolecular viscosity of the dough (Padalino, Conte, & Del Nobile, 2016). XG can be used for processing gluten-free food products due to its non-Newtonian fluid properties with high pseudoplasticity and non-gelling properties. The specific shear thinning flow behavior and weak gelling properties of XG provides excellent suspension and coating properties with assistance in easy mixing, pouring and swallowing application (Lopes, Lessa, Silva, & La Cerda, 2015).

Inulin is a type of oligosaccharide which is regarded as prebiotic dietary fiber (Morreale, Benavent-Gil, & Rosell, 2019). The inulin has the effect of lowering the glycemic index, improving gut health, lowering triglyceride and cholesterol levels (Aravind, Sissons, Fellows, Blazwk & Gilbert, 2012). Inulin serves various health functions including its action as dietary fiber, enhance calcium absorption; regulate food intake and appetite; and stimulate the immune system (Shoaib et al., 2016). The defatted rice bran which is rich in protein, dietary fiber and bioactive compounds, has great potential in the development of the value-added food products with increased nutritional quality without compromising the eating quality of the food (Sivamaruthi, 2018). Furthermore, the inulin and rice bran have been reported to reduce the risk of several diseases such as coronary heart diseases, insulin sensitivity, high blood pressure and cholesterol level, hyperlipidemia, hyperglycemia, osteoporosis and diabetes (Sharma, Srivastava, & Saxena, 2015).

To date, no study has been yet reported on the development of low glycemic gluten-free noodle with resistant starch. Therefore, this research study aims to develop the gluten free noodles utilizing the native autoclaved Pathumthani 80 (RD 31) resistant starch along with the addition of xanthan gum, inulin and defatted rice bran for the improvement of texture and reduction of glycemic index of the gluten free noodles.

2. Materials and methods

2.1. Materials

Rice samples Pathumtani 80 (RD 31) were obtained from the Pathum Thani Rice Research Center, Ministry of Agriculture and Cooperative (MoAC), Thailand. The resistant starch and glycemic index test kits were bought from Megazyme International Ireland Ltd., Ireland. All other analytical grade chemicals and reagents were acquired from Sigma-Aldrich, Switzerland.

2.2. Preparation of resistant starch

Pathumthani 80 (RD 31) rice was used to prepare resistant starch (type III) following the method as described by Raungrusmee and Anal (2019). Initially, native rice starch was extracted from RD 31 by alkaline treatment with sodium hydroxide (0.35% w/v, 1:2) at 4 °C for 24 h. The extracted native starch was subjected to autoclaving-cooling treatment to modify to resistant starch (type III). Native rice starch in water (1:10 w/w) was pregelatinized in a water bath (Memmert: WNB 22, Germany) maintained at 85 °C for 30 min followed by autoclaving (Hirayama: HVE-50, Japan) at 135 °C for 30 min, cooling and storing at 4 °C for 24 h. This process of autoclaving and cold storing processes was repeated for three times. Finally, the autoclaved starch was dried in hot air oven at 50 °C, ground (Panasonic, MS-AC300, Japan), sieved through 100 meshes (Laboratory test sieve BS410-1 Endecotts Ltd, London, England), vacuum packed in high-density polyethylene (HDP) pouch and stored in the desiccators.

2.3. Preparation of gluten-free noodle

The gluten free noodles were prepared by following the method of Yalcin and Basman (2008) with slight modifications. The gluten-free noodles were prepared using the formulation: RD 31-NARS (100 g), whole egg (30 g), salt (3 g), sodium bicarbonate (3 g), distilled water (45 mL). Gluten-free noodle preparation was done in following steps: first xanthan gum (XG) at different concentration (0.625, 1.25, 2.5 and 5%) was added in order to improve the texture of gluten-free noodle. Gluten-free noodle without XG was used as control. Finally, inulin and defatted rice bran at different concentration (5% w/w) were added in the gluten-free XG noodle with the aim of reducing the glycemic index. In this step, wheat flour noodle was used as control. Noodle dough was prepared using dough mixture followed by sheeting in noodle maker (Atlas 150 Pastabike: Marcato, Italy) and noodles were cut to uniform size (1 mm thickness × 1 mm width). The noodles were cooked at 60 °C in hot water until cooked followed by cooling and sealing in polyethylene bag for further analysis.

2.4. Determination of resistant starch

Resistant, non-resistant and total starch contents of the sample were determined enzymatically using the Megazyme resistant starch assay test kit (Megazyme International Ltd., Ireland). The sample (100 mg) was incubated with mixture (4 mL) of pancreatic amylase (10 mg/mL) and amyloglucosidase (3U/mL) in shaking water bath (Eyela, Model SB-651, Japan) for 16 h at 37 °C, followed by the addition of 4 mL ethanol (99%, v/v) and centrifugation (3000 rpm for 10 min) to terminate enzymatic reaction. The supernatant was separated for the estimation of non-resistant starch. After removing the supernatant, the pellet was mixed with ethanol (50%, v/v, 8 mL) and centrifuged (3000 rpm, 10 min), followed by the decantation of the supernatant. The resistant starch was recovered as a pellet and mixed with 2 M KOH (2 mL) and stirred in ice bath for 20 min, followed by addition of sodium acetate buffer (8 mL, pH 3.8) and amyloglucosidase (3300 U/mL, 0.1 mL). The mixture was incubated at 50 °C for 30 min and then centrifuged (3000 rpm. 10 min). The supernatant (0.1 mL) was added to glucose oxidase-peroxidase- amino antipyrine (GOPOD) (3 mL) and incubated (50 °C for 20 min). The absorbance of the mixture was measured using spectrophotometer (Gene Quant 1300, USA) at 510 nm. The resistant starch, non-resistant starch and the total starch contents were measured using equations (1)–(3) respectively.

$$\boldsymbol{Resistant\ starch} = \Delta \boldsymbol{E}_1 \times \frac{\boldsymbol{F}}{\boldsymbol{W}} \times 90 \tag{1}$$

$$\boldsymbol{Non-resistant\ starch} = \Delta \boldsymbol{E}_2 \times \frac{\boldsymbol{F}}{\boldsymbol{W}} \times 90 \tag{2}$$

$$\boldsymbol{Total\ starch} = \boldsymbol{Resistant\ starch} + \boldsymbol{Non-resistant\ starch} \tag{3}$$

Where,

ΔE_1 = absorbance of resistant starch sample-absorbance of blank, ΔE_2 = absorbance of non-resistant starch sample-absorbance of blank, F = 100 (μg of D-glucose) divided by the GOPOD absorbance for this 100 μ g of D-glucose, W = dry weight of sample analyzed.

2.5. Determination of glycemic index (GI)

The *in-vitro* glycemic index (GI) of the sample was determined following the method of Goñi, Garcia-Alonso, and Saura-Calixto (1997), with slight modifications. Glucose concentration was analyzed using a glucose oxidase-peroxidase kit (Megazyme International Ireland Ltd., Ireland). Hydrolysis curves were built, and the area under the hydrolysis curves was calculated (AUC). The hydrolysis index (HI) for each sample was calculated as the ratio between the AUC of the sample and reference sample (white bread) and expressed in percentage. Finally, the glycemic index was calculated by using equation (4):

$$Glycemic\ index\ (\%) = 39.71\ + (0.549\ \times Hydrolysis\ Index) \tag{4}$$

2.6. Cooking time

Cooking time of noodles was determined by slightly modified method of Kaur, Shevkani, Singh, Sharma, & Kaur, 2015. Briefly, 25 g of sample noodle was cooked in 300 mL of boiling distilled water in a 600 mL beaker. Cooking time was determined as the time required for the disappearance of white core as judged by squeezing the noodle between two glass slides.

2.7. Water absorption and cooking loss of noodle

Cooking loss and water absorption were analyzed by following Kang et al. (2017). In 300 mL of boiling water 25 g of noodles sample was cooked at a previously determined optimum cooking time. Noodles were strained and the cooked water was collected in a beaker and then solid material was determined in the cooking water by evaporating in a hot air oven at 105 °C overnight until a constant weight was reached. The water absorption and cooking loss of noodles were determined by equations (5) and (6) respectively.:

$$Water\ absorption\ (\%) = \frac{weight\ of\ (cooked\ noodle - fresh\ noodle)}{weight\ of\ fresh\ noodle} \times 100 \tag{5}$$

$$Cooking\ loss\ (\%) = \frac{remaining\ solid\ content\ after\ drying}{weight\ of\ fresh\ noodle} \times 100 \tag{6}$$

2.8. Texture analysis

The texture analysis of noodles was evaluated using the texture analyzer (Stable Micro Systems Analyzers: TA-XT plus, England). Instrument settings were extension mode; trigger type, 5 g; pretest speed 3.0 mm/s; posttest speed 5 mm/s; test speed 3.0 mm/s; and trigger distance 80 mm. From force-distance curves, two texture parameters were obtained: tensile strength (maximum force; g) and breaking length (mm) (Lu, Guo, & Zhang, 2009). Noodle firmness was determined following Khouryieh, Herald, and Aramouni (2006) with slight modification. A noodle blade (5 × 5 cm) was used to compress the cooked noodles. Texture parameter were set as pretest speed = 0.5 mm/s; test speed = 0.2 mm/s; posttest speed = 10 mm/s and distance of 5.5 mm. Five cooked noodles were placed parallel and compressed by the noodle blade to a distance of 5.5 mm.

2.9. Color attributes

Color spectra of samples were determined by using a Hunter-Lab spectrophotometer (Color Flex: 45/0, USA). Sample (10 g) was placed in the glass container and placed over the slit of the instrument. The average value of ten measurements was reported and showed as L* (lightness), a* (redness) and b* (yellowness) values.

2.10. Sensory evaluation

Sample noodles were presented to the 50 panelists for the evaluation of sensory attributes (appearance, color, flavor, softness, stickiness and overall liking). The panelists were asked to compare samples and nine-point hedonic scale (1 = disliked extremely, 9 = liked extremely) was used (Hlaing, Sadiq, & Anal, 2019).

2.11. Proximate analysis

Proximate composition (%) of the samples including moisture, ash, protein, fat, crude fiber, and carbohydrate content, was determined in triplicate following AOAC (2012) methods.

2.12. Scanning electron microscopy

The microstructural images of the sample were taken using scanning electron microscope (SEM) (JSM 6310F, Japan). The sample were mounted on specimen stubs using adhesive tape. Samples were coated with gold particles and observed using SEM with 5000× magnification at an accelerating voltage of 5 kV.

2.13. Fourier transform infrared (FTIR) spectroscopy analysis of gluten free noodles

The infrared spectra of the samples were measured using an attenuated total reflectance (ATR) Fourier transform infrared spectrometer (FTIR) (Alpha-E: BRUKER, Germany). Sample was used directly for the measurement of the spectrum from 500 to 4000 cm^{-1} wave numbers.

2.14. Differential scanning colorimetry (DSC)

DSC of samples was performed following the method of Singh, Kaur, Shevkani & btenn (2015). The sample (2 g) was placed into a hermetically sealed sample pan. DSC (Module: Mettler Toledo, Schwerzenbach Switzerland) was performed in the temperature range of 25–200 °C at a heating rate of 10 °C/min. After heating, the sample was cooled to 25 °C, and the DSC curves were obtained.

2.15. Statistical analysis

The analysis of variance (ANOVA) and Tukey's HSD test were performed by SPSS version 23 (SPSS, IBM, Chicago USA) to determine the significant differences ($p < 0.05$) among the mean observations.

3. Result and discussion

3.1. Resistant starch and glycemic index of starch

Pathumthani 80 (RD 31) native rice starch (RD 31-NRS) was autoclaved to produce native autoclaved resistant starch (RD 31-NARS) and was utilized to develop gluten-free low glycemic noodle. The resistant starch content of native starch (8.44%) was observed to increase significantly with autoclaving treatment in RD 31-NARS (64.95%) while the glycemic index (GI) of native starch (66.32%) was significantly higher than that of RD 31- NARS (46.12%). In relation to resistant starch, higher the content of resistant starch, higher is the resistance to digest and subsequently slower is the digestion which lowers the glycemic index. Resistant starch decreases the glycemic index of food as it decreases the postprandial glucose and human body's insulin response thereafter (Smrčková et al., 2014). Mestres, Colonna, and Buléon (1988) also reported that starch noodles were essentially retrograded starch, which showed a slow digestibility pattern.

3.2. Effect of xanthan gum on quality of gluten free noodles

Due to absence of gluten protein, rice starch lacks the physical functionality provided by the gluten which limits the application of rice flour in noodle preparations. However, the rice noodle quality can be improved by the addition of polysaccharide gums. The hydrogen bonding between inner and exterior chains of starch and polysaccharide gum mixture develops a rigid and stable gluten like network (Chung et al., 2012) and helps to improve dough viscosity, structure, texture and increase the dietary fiber content (Padalino et al., 2016). Therefore,

Table 1
Resistant starch, non-resistant starch, total starch and glycemic index of gluten-free noodle prepared from RD 31-native autoclaved resistant starch and xanthan gum.

Xanthan gum (%)	Resistant starch	Non-resistant starch	Total starch	Glycemic index (%)
0	47.22 ± 2.09^{a}	45.60 ± 2.70^{ab}	92.82 ± 1.10^{a}	50.15 ± 0.04^{d}
0.625	44.06 ± 1.07^{b}	44.61 ± 3.17^{b}	88.66 ± 3.08^{a}	51.05 ± 0.06^{c}
1.25	36.76 ± 0.87^{c}	52.99 ± 3.20^{a}	89.76 ± 2.42^{b}	52.63 ± 0.00^{b}
2.5	24.90 ± 1.61^{d}	45.17 ± 3.16^{b}	70.07 ± 1.62^{b}	52.78 ± 0.16^{b}
5	18.40 ± 1.29^{e}	42.01 ± 1.70^{b}	60.41 ± 2.69^{d}	61.15 ± 0.62^{a}

Results are mean of triplicate determinations ± S.D.
Different superscripts within a column denote statistically significant differences ($p < 0.05$).

the effect of XG at different levels (0.625, 1.25, 2.5 and 5%) on RD 31-NARS gluten-free noodles was analyzed in terms of resistant starch content and glycemic index, cooking quality, textural, color and sensory properties.

3.2.1. Resistant starch and glycemic index

The increase in the concentration of XG (0.625–5%) resulted a significant ($p < 0.05$) decrease in resistant starch content, whereas, the glycemic index was increased significantly (Table 1). The highest glycemic index was exhibited by the noodle with the highest amount of XG (5% w/w) except which all other noodle samples were categorized as low glycemic index food. The results are in agreement with Srikaeo, Laothongsan, and Lerdluksamee (2018) who reported an increase in rate of starch digestion and glycemic index of dried-natural fermented rice noodles with the addition of XG. This increase has been proposed because of effect of hydrocolloids on pattern of starch fraction, hydration of starch, and the microstructure of noodles. Similarly, Milde, Chigal, and Chiola Zayas (2018) reported a decrease in resistant content of the gluten-free noodle made from cassava starch with the addition of 0.6% XG.

3.2.2. Cooking quality, texture and color

The increase in percentage of XG on RD 31-NARS gluten-free noodle exhibited non-significant ($p \geq 0.05$) increase in the cooking time and decrease in cooking loss. However, there was significant increase on water absorption of noodles with the increase in percentage of XG (Table 2). This increase in water absorption with the increase in XG concentration is due to its ability to interact with amylopectin at long exterior chains (amylose-like component), leading to the increase of viscosity and water absorption during heating (Srikaeo et al., 2018). Further, the double helical structure and multiple spiral polymer secondary structure form of XG are also responsible for the improvement of water holding capacity (Pan, Ai, Wang, Wang, & Zhang, 2016).

The RD 31-NARS gluten-free noodles with and without XG were subjected to textural analysis. The tensile strength and elasticity of RD 31-NARS gluten-free noodles without XG was not detected which might be due to weak rice protein network in absence of gluten protein. However, there was no significant change in the tensile strength with the increase in the concentration of XG (Table 2). Firmness and tensile strength of RD 31-NARS gluten-free noodle with 5% XG showed the highest value. Addition of XG has been reported to facilitate gel matrix formation but with the interference in gel compactness developing undesirable noodle properties (Kim & Yoo, 2006). Additionally, color is one of the most important factors in determining consumer acceptance. The increasing concentration of XG in RD 31-NARS gluten free noodles did not show any significant change in L*, a* and b* values (Table 2 and Supplementary Fig. 1).

3.2.3. Sensory evaluation

Sensory attributes of RD 31-NARS gluten-free noodles were analyzed (Table 3). The noodles with 2.5% XG received the highest score indicating its possibility for the development of gluten free noodles with sensory attributes like wheat flour noodle. Thus, from functional and sensory analysis, gluten free noodle with 2.5% XG was selected for further experiments.

3.3. Effect of addition of inulin and defatted rice bran on RD 31-NARS gluten-free noodles

Inulin and defatted rice bran at 5% concentration were added separately to RD 31-NARS gluten-free noodles containing XG (2.5%) for the development of a low glycemic food and to improve the noodle

Table 2
Cooking quality, texture and color of cooked gluten-free noodles prepared from resistant starch and xanthan gum.

Characteristic	Xanthan gum (%)				
	0	0.65	1.25	2.5	5
Cooking quality					
Cooking Time (min)^{ns}	11.50 ± 0.71	11.50 ± 0.71	12.00 ± 0.00	13.00 ± 1.41	14.00 ± 0.00
Cooking Loss (%) ^{ns}	3.96 ± 0.08	2.75 ± 0.43	2.64 ± 1.91	2.67 ± 2.12	2.19 ± 0.02
Water Absorption (%)	12.00 ± 0.00^{c}	40.50 ± 0.71^{b}	53.50 ± 0.71^{ab}	62.00 ± 8.49^{a}	63.00 ± 1.41^{a}
Texture					
Tensile strength (N)^{ns}	ND	0.25 ± 0.00	0.36 ± 0.01	0.39 ± 0.00	0.75 ± 0.49
Elasticity (mm)	ND	16.39 ± 0.00^{b}	21.09 ± 4.12^{ab}	23.98 ± 0.00^{ab}	25.19 ± 3.86^{a}
Firmness (N)	0.08 ± 0.05^{b}	0.42 ± 0.25^{b}	0.31 ± 0.00^{b}	0.37 ± 0.03^{b}	1.05 ± 0.06^{a}
Color					
L^{*ns}	45.90 ± 4.98	45.53 ± 2.43	46.21 ± 8.56	49.37 ± 1.89	54.48 ± 0.93
a^{*ns}	2.96 ± 1.01	2.70 ± 1.39	3.13 ± 1.44	3.35 ± 1.49	3.59 ± 1.26
b^{*ns}	13.13 ± 5.55	14.06 ± 4.60	14.22 ± 0.01	16.61 ± 3.15	16.35 ± 5.03

Results are mean of triplicate determinations ± S.D.
Different superscripts with in one row denote statistically significant differences ($p < 0.05$).
ns denotes that means within a row were not statistically different ($p \geq 0.05$).
L (lightness), ± a redness/greenness, ± b (yellowness/blueness).

Table 3
Sensory evaluation of gluten free noodles prepared from resistant starch and xanthan gum.

Xanthan gum (%)	Attributes					
	Appearance ^{ns}	Color ^{ns}	Flavor	Softness ^{ns}	Stickiness	Overall liking
0	6.23 ± 1.59	6.07 ± 1.32	5.54 ± 1.94 ^{b}	5.23 ± 1.69	5.15 ± 1.35^{b}	5.38 ± 1.71 ^{b}
0.625	6.69 ± 0.95	6.77 ± 1.54	6.46 ± 0.55 ^{a}	6.54 ± 1.71	6.38 ± 1.32^{ab}	6.46 ± 0.88 ^{ab}
1.25	6.77 ± 1.01	6.77 ± 1.79	6.54 ± 1.27 ^{a}	6.54 ± 1.94	6.46 ± 1.20^{a}	6.62 ± 1.04 ^{ab}
2.5	7.23 ± 0.93	7.00 ± 0.91	6.85 ± 0.99 ^{a}	7.00 ± 1.35	6.85 ± 1.21^{a}	7.08 ± 1.32 ^{a}
5	7.06 ± 0.82	6.92 ± 1.04	6.62 ± 1.19 ^{a}	6.77 ± 1.24	6.54 ± 1.20^{a}	6.69 ± 1.38 ^{ab}

Results are mean of triplicate determinations ± S.D.
Different superscripts with in one column denote statistically significant differences ($p < 0.05$).
ns superscripts within one column denote means were not significantly different ($p \geq 0.05$).

texture.

3.3.1. Resistant starch and glycemic index

The wheat flour noodle exhibited the lowest resistant starch content (18.4%) and the highest glycemic index (65.4%). The RD 31-NARS gluten-free noodle with XG (2.5%) exhibited significantly ($p < 0.05$) lower resistant starch content (24.90%) compared with the gluten-free noodle without XG (47.22%). Meanwhile, RD 31-NARS gluten-free noodle with XG (2.5%) exhibited significant decrease ($p < 0.05$) in the resistant starch content with the addition of inulin (29.19%) and defatted rice bran (27.14%) (Table 4). Inulin acts as a dietary fiber that is resistant to enzymatic digestion (Shoaib et al., 2016), hence the gluten-free noodle with XG (2.5%) and inulin (5%) had the higher percentage of resistant starch higher than the gluten-free noodle with XG (2.5%).

Further, RD 31-NARS gluten-free noodle with XG (2.5%) exhibited significantly ($p < 0.05$) higher glycemic index value (52.78%) compared to that of gluten-free noodle with added inulin (49.20%) and defatted rice bran (48.01%). This indicates that RD 31-NARS gluten free noodles mixed with XG, inulin and defatted rice bran were effective at lowering the glycemic index. The glycemic index of gluten-free noodles with the addition of inulin and rice bran ranged from around 48–49, thus, the noodle sample are classified as low glycemic food (Raungrusmee & Anal, 2019). Inulin serves to reduce glycemic index value following the reduction in the starch digestibility (Delgado & Bañón, 2018) due to its ability to form a semisolid gel matrix encasing the starch (Brennan, Kuri, & Tudorica, 2004) and reduction in the available moisture for starch gelatinization (Brasil et al., 2011). Moreover, defatted rice bran is rich source of dietary fiber which envelops starch and protect from the amylolytic enzymes and thus impinge the release of free glucose, resulting in a reduced glycemic response (Juvonen et al., 2009). The experimental results showed that the addition of inulin and defatted rice bran could inhibit the *in vitro* digestion and starch hydrolysis to a certain extent, thereby reducing the glycemic index value of gluten-free noodle.

3.3.2. Cooking quality

RD 31-NARS with XG (2.5%) gluten-free noodles exhibited significant increase ($p < 0.05$) in cooking time and water absorption with the addition of inulin (5%) and defatted rice bran (5%) (Table 5). The reduced water absorption exhibited in the gluten-free noodle samples with added inulin may be explained by the highly hydrophilic characteristics of inulin. It is likely that the inulin preferentially absorbs the water, resulting inhibition of starch swelling and reduced water absorption capacity of noodle sample (Brennan et al., 2004). The increase in water absorption capacity of noodle with added inulin is found to be related to the presence of –OH group in inulin fiber responsible for H-bonding (Afshinpajouh, Adeyemi, Akinwande, Kulakow & Maziya-Dixon, 2014). Further, no significant difference was observed in the cooking loss among the samples.

3.3.3. Texture

The textural properties of RD 31-NARS gluten-free noodles with added XG (2.5%), inulin (5%) and defatted rice bran (5%) were evaluated and expressed in terms of tensile strength, elasticity and firmness (Table 5). Addition of inulin and defatted rice bran in the gluten-free noodle exhibited significant ($p < 0.05$) increase in firmness; however, tensile strength and elasticity decreased significantly ($p < 0.05$). Brennan et al. (2004), reported no significant difference in stickiness of pasta with the addition of inulin which might be due to the elasticity of inulin being similar to the control sample. The reduction in starch swelling within the samples containing inulin and rice bran might be due to preferential hydration of inulin and rice bran, followed by aggregation and formation of semisolid gel (Mastronatteo, Iannetti, Civia, Sepielli & Del Nobile, 2012).

3.3.4. Color

The color parameters of cooked RD 31-NARS gluten-free noodles added with inulin and defatted rice bran were evaluated (Table 5). Noticeably, the gluten-free noodles made from the RD 31-NARS were darker compared with the wheat flour noodles. It was due to non-enzymatic conjugation reaction between reducing sugar from the autoclaved starch and amino group in the proteins (Balasubramanian, Sharma, Kaur, & Bhardwaj, 2014).

3.3.5. Sensory

According to the result of sensory analysis, RD 31-NARS gluten free

Table 4
Resistant starch, non-resistant starch, total starch and glycemic index of RD 31-NARS gluten free noodles, containing xanthan gum, inulin and rice bran.

Noodle Sample	Resistant starch (%)	Non-Resistant starch (%)	Total Starch (%)	Glycemic Index (%)
WF	18.40 ± 1.29^{d}	42.01 ± 1.70^{ab}	60.41 ± 2.69^{d}	65.40 ± 0.10^{a}
RD 31-NARS	47.22 ± 2.09^{a}	45.60 ± 2.70^{a}	92.82 ± 1.10^{a}	44.23 ± 0.01^{e}
RD 31-NARS + XG (2.5%)	24.90 ± 1.61^{c}	45.17 ± 3.16^{a}	70.07 ± 1.62^{ab}	52.78 ± 0.16^{b}
RD 31-NARS + XG (2.5%) + Inulin (5%)	29.19 ± 2.28^{b}	38.48 ± 7.94^{b}	67.67 ± 6.27^{c}	49.20 ± 0.06^{c}
RD 31-NARS + XG (2.5%) + Rice bran (5%)	27.14 ± 0.84^{bc}	44.78 ± 4.08^{a}	71.92 ± 4.75^{b}	48.01 ± 0.56^{d}

Results are mean of triplicate determinations ± S.D Means within columns.
Different superscripts with in one column denote statistically significant differences ($p < 0.05$).
WF = Wheat flour; RD 31-NARS = RD 31-Native autoclaved resistant starch; XG = Xanthan gum.

Table 5

Cooking quality, texture and color of RD 31-NARS gluten free noodle prepared with xanthan gum, inulin and rice bran.

Characteristic	WF	RD 31-NARS	RD 31-NARS + XG (2.5%)	RD 31-NARS + XG (2.5%) + Inulin (5%)	RD 31-NARS + XG (2.5%) + Rice bran (5%)
Cooking quality					
Cooking Time (min)	5.01 ± 0.01^{d}	12.00 ± 0.00^{c}	13.00 ± 1.41^{c}	27.50 ± 1.41^{b}	29.50 ± 212^{a}
Cooking Loss ^{ns} (%)	0.70 ± 0.01^{b}	2.19 ± 0.01^{a}	2.67 ± 2.12^{a}	2.24 ± 0.03^{a}	2.58 ± 0.03^{a}
Water Absorption (%)	19.24 ± 0.01^{d}	40.10 ± 0.06^{c}	62.00 ± 8.49^{b}	79.85 ± 0.08^{a}	80.76 ± 0.71^{a}
Texture					
Tensile strength (N)	0.59 ± 0.01^{a}	ND	0.39 ± 0.00^{b}	0.24 ± 0.01^{c}	0.21 ± 0.04^{c}
Elasticity (mm)	38.56 ± 2.04^{a}	ND	21.09 ± 4.12^{b}	16.49 ± 2.23^{c}	14.03 ± 1.82^{c}
Firmness (N)	0.06 ± 0.01^{d}	0.08 ± 0.50^{d}	0.37 ± 0.03^{c}	0.78 ± 0.03^{b}	1.59 ± 0.14^{a}
Colour					
L*	48.06 ± 0.06^{c}	35.35 ± 0.01^{d}	45.90 ± 0.11^{c}	45.88 ± 0.11^{b}	48.99 ± 0.02^{a}
a*	4.15 ± 0.01^{b}	1.97 ± 0.01^{d}	3.59 ± 1.26^{c}	5.17 ± 0.02^{a}	4.92 ± 0.11^{a}
b*	17.32 ± 0.01^{b}	13.55 ± 0.01^{c}	16.61 ± 3.15^{b}	21.03 ± 0.66^{a}	22.03 ± 0.11^{a}

Results are mean of triplicate determinations ± S.D.
Different superscripts with in one row denote statistically significant differences ($p < 0.05$).
ns means non-significant difference ($p \geq 0.05$); ND = Not detected.
RD 31-NARS = RD 31-Native autoclaved resistant starch; XG = Xanthan gum.

Table 6

Sensory characteristics of RD 31-NARS gluten free noodle prepared with xanthan gum, inulin and rice bran.

Noodle Sample	Attributes					
	Appearance	Color	Flavor	Softness	Stickiness	Overall liking
WF	7.85 ± 0.90^{a}	8.00 ± 0.57^{a}	7.85 ± 0.55^{a}	8.15 ± 0.69^{c}	7.85 ± 0.90^{a}	8.08 ± 0.76^{a}
RD 31-NARS	6.23 ± 1.59^{b}	6.08 ± 1.32^{c}	5.54 ± 1.94^{b}	5.23 ± 1.69^{d}	5.15 ± 1.34^{c}	5.38 ± 1.71^{c}
RD 31-NARS + XG (2.5%)	7.77 ± 0.93^{a}	7.08 ± 1.04^{ab}	6.77 ± 1.09^{ab}	7.08 ± 0.76^{c}	6.15 ± 0.99^{bc}	6.15 ± 0.90^{bc}
RD 31-NARS + XG (2.5%) + Inulin (5%)	6.23 ± 1.17^{b}	6.54 ± 0.78^{bc}	6.92 ± 0.95^{a}	6.46 ± 0.78^{b}	6.46 ± 0.97^{b}	6.85 ± 0.99^{b}
RD 31-NARS + XG (2.5%) + Rice bran (5%)	7.08 ± 0.86^{ab}	7.08 ± 0.76^{ab}	7.15 ± 0.90^{a}	7.00 ± 0.71^{a}	7.00 ± 0.91^{ab}	7.23 ± 0.83^{ab}

Results are mean of triplicate determinations ± S.D.
Different superscripts with in one column row denote statistically significant differences ($p < 0.05$).
ns mean non-significant difference ($p \geq 0.05$).

noodles with XG (2.5%) and inulin (5%) and RD 31-NARS noodles with XG (2.5%) and defatted rice bran (5%) got significantly ($p \geq 0.05$) high scores for color, flavor, stickiness and overall liking acceptability compared with gluten free noodles without inulin and rice bran (Table 6). The addition of inulin and rice bran did not have significant ($p \geq 0.05$) effect on color and flavor parameters compare with RD-31 NARS gluten-free noodle with XG (2.5%). This might be due to the bland flavor of rice and neutral taste of inulin that has minimum effect on the organoleptic characteristics of the products (Aravind, Sissons, Fellows, Blazek, & Gilbert, 2012).

3.3.6. *Proximate analysis*

The proximate compositions of wheat flour noodles, RD 31- NARS gluten-free noodle with XG (2.5%), along with addition of inulin (5%) and defatted rice bran (5%) were analyzed (Table 7). The moisture content of gluten-free noodles was lower than the wheat flour noodle indicating the better storage quality of gluten-free noodles. The protein content of gluten-free noodles was significantly ($p < 0.05$) lower than the wheat flour noodle which was mainly due to the absence of gluten protein (Wakil & Onilude, 2009). Among the gluten-free noodles, RD 31-NARS with XG noodle (2.5%) and defatted rice bran (5%) exhibited the highest protein content (4.62 ± 0.03%), fiber (0.35 ± 0.01%) and ash content (1.45 ± 0.07%) which was due to the rice bran protein mainly composed of lysine (Chandi & Sogi, 2007). This indicates that rice bran is a good source of protein and fiber that can be used for the development of various functional food products (Abdul-Hamid & Luan, 2000). Further, fat content and carbohydrate content of gluten-free noodles were significantly higher than the wheat flour noodle.

Table 7

Proximate analysis of RD 31-NARS gluten free noodle prepared with xanthan gum, inulin and rice bran.

Noodle Sample	Moisture content (%)	Protein (%)	Fat (%)	Crude fiber (%)	Ash (%)	Carbohydrate (%)
WF	67.92 ± 0.02^{a}	5.16 ± 0.08^{a}	0.02 ± 0.00^{d}	0.11 ± 0.03^{b}	0.20 ± 0.03^{d}	26.60 ± 0.16^{e}
RD 31-NARS	58.70 ± 0.04^{b}	4.42 ± 0.06b^{c}	0.81 ± 0.06^{c}	0.09 ± 0.02^{b}	1.15 ± 0.10^{b}	34.85 ± 0.21^{d}
RD 31-NARS + XG (2.5%)	51.18 ± 0.25^{d}	4.45 ± 0.02^{b}	1.49 ± 0.02^{a}	0.13 ± 0.04^{b}	1.32 ± 0.06^{ab}	41.45 ± 0.12^{b}
RD 31-NARS + XG (2.5%) + Inulin (5%)	55.22 ± 0.08^{c}	4.22 ± 0.06^{c}	0.86 ± 0.02^{c}	0.12 ± 0.01^{b}	0.83 ± 0.09^{c}	38.77 ± 0.26^{c}
RD 31-NARS + XG (2.5%) + Rice bran (5%)	42.66 ± 0.33^{e}	4.62 ± 0.03^{b}	1.16 ± 0.14^{b}	0.35 ± 0.01^{a}	1.45 ± 0.07^{a}	49.77 ± 0.40^{a}

Results are mean of triplicate determinations ± S.D.
Different superscripts within same column denote statistically significant differences ($p < 0.05$).
WF= Wheat flour.
RD31-NARS = RD 31-native autoclaved resistant starch.
XG = Xanthan gum.

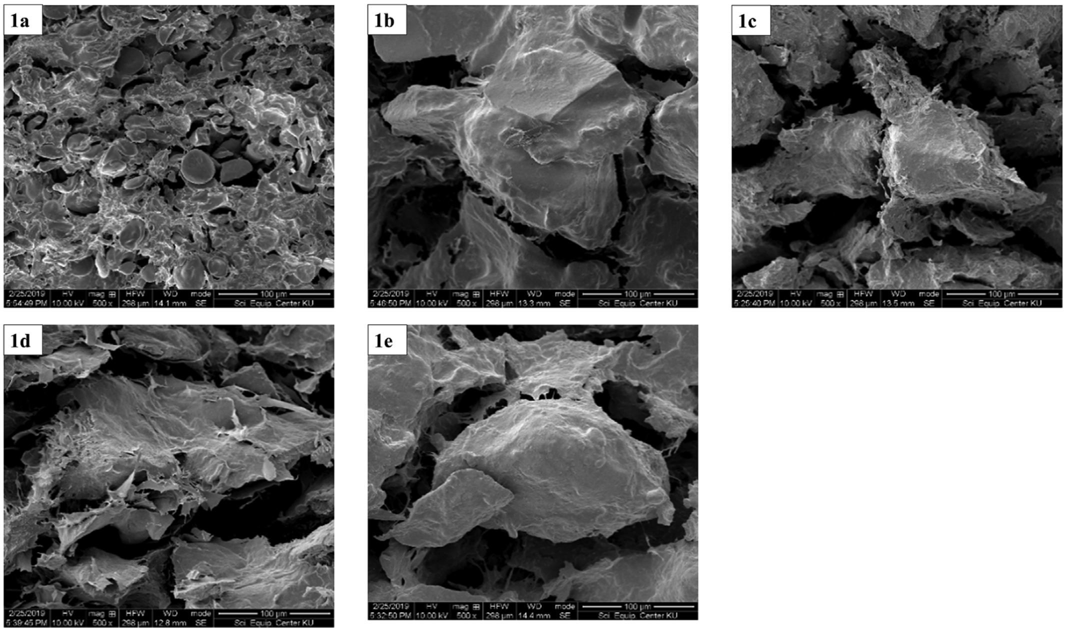

Fig. 1. Microstructure of wheat noodle (1a); gluten free noodle from the RD 31- native autoclaved resistant starch (1b); RD 31-native autoclaved resistant starch + xanthan gum (2.5%) noodle (1c); RD 31- native autoclaved resistant starch with xanthan gum (2.5%) and inulin (5%) noodle (1d); RD 31-native autoclaved resistant starch with xanthan gum (2.5%) and rice bran (5%) noodle (1e).

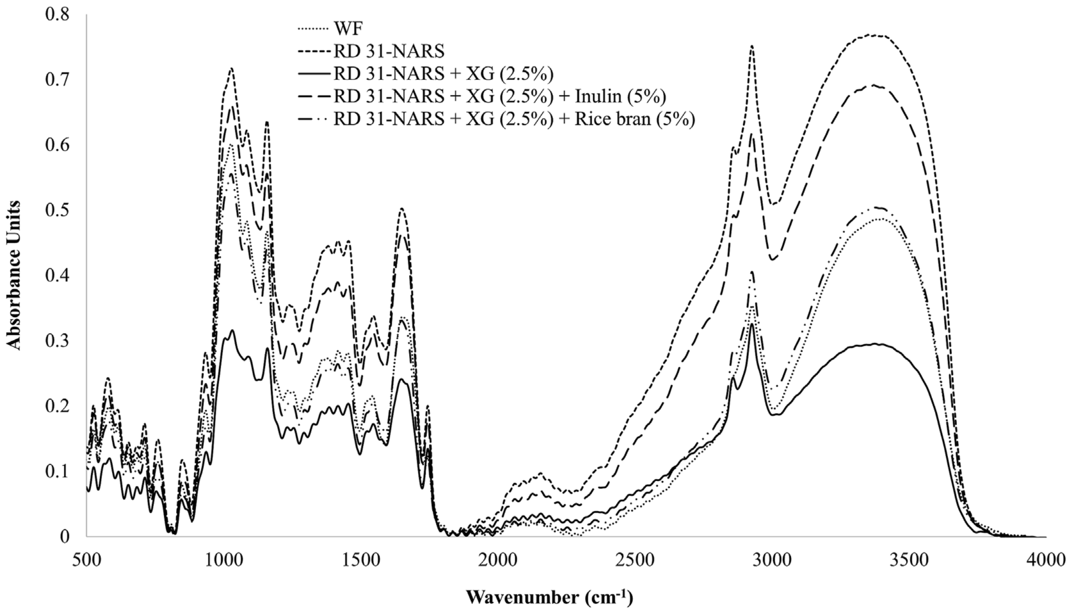

Fig. 2. FTIR spectra of RD 31-NARS gluten free noodles with xanthan gum, inulin and rice bran. Where, WF = wheat flour noodle, RD 31 NARS = rice native autoclaved resistant starch, XG = xanthan gum.

Table 8
Thermal properties of gluten free noodle from RD 31-NARS with xanthan gum, inulin and rice bran.

Noodle sample	T peak (°C)	T Onset (°C)	T End set (°C)	ΔH (Jg^{-1})
RD 31-NARS + XG (2.5%)	165.50	152.70	172.85	−4787.19
RD 31-NARS + XG (2.5%) + Inulin (5%)	137.83	146.60	146.76	−5604.11
RD 31-NARS + XG (2.5%) + Rice bran (5%)	138.17	118.32	147.93	−6691.51

RD 31- NARS = RD 31-native autoclaved resistant starch; XG = Xanthan gum.

3.3.7. Scanning electronic microscopy

The effect of different formulation on the microstructures of noodles from wheat flour alone; RD 31- NARS alone; RD 31- NARS with XG (2.5%); RD 31 -NARS with XG (2.5%) and inulin (5%); and RD 31-NARS with XG (2.5%) and defatted rice bran (5%) were studied by using scanning electron microscopy (SEM) (Fig. 1). Wheat flour-based noodles (Fig. 1a) showed well developed protein network compared to gluten free noodles. Within gluten free noodles, the addition of XG, defatted rice bran and inulin induced slight porosity and hollow structure (Fig. 1c, d and 1e) compared to gluten free noodles made with resistant rice starch alone (Fig. 1b).

Similarly, Javaid et al. (2018) reported appearance of porous microstructure in fresh potato instant noodles with the addition of XG. The SEM images are consistent with the cooking qualities of the noodles (Table 5) such that the porous structure is responsible for the higher cooking loss with the addition of XG, inulin and defatted rice bran. Moreover, Susanna and Prabhasankar (2013) observed the effect of xanthan gum in the maize-field bean pasta that starch molecules encapsulated within the xanthan network have an impact on reduced starch leaching during cooking and develop a smoother and more consistent internal structure with partly swollen starch granules embedded inside the protein-hydrocolloid matrix. Aravind et al. (2012) reported the effects of inulin addition on durum wheat spaghetti and found that inulin addition was associated with more open structures and compact formation, possibly due to greater protein–fiber interaction. Whereas, the porous microstructure of gluten-free noodle with rice bran decreased the air pockets, which was in agreement with Zhang, Li, Li, & Liu (2019), who showed that adding dietary fiber increased elasticity of starch gels by immobilizing water.

3.3.8. FTIR analysis of gluten free noodles

FTIR analysis was carried out for further confirmation of compatibility of the RD 31-NARS blended with XG (2.5%), rice bran (5%) and inulin (5%) compared with wheat noodle (Fig. 2). In all spectra, composite variation mode in the region below 800 cm^{-1} was related to the pyranose ring in the glucose unit. The anhydrous glucose ring O=C stretching was represented by the peak between 990 cm^{-1} and 1030 cm^{-1}. RD 31-NARS gluten-free noodles showed higher intensity at 1000 cm^{-1} which indicates that autoclaving treatment causes more efficient packing of double helices within the crystalline lamella (Ashwar et al., 2016). Nevertheless, RD 31-NARS gluten-free noodle can be used to investigate the C–H stretching region at approximately 2800–3000 cm-1 .

The spectral region between 900 and 1200 cm^{-1} was generally dominated by a complex sequence of intensive peaks mainly due to strongly coupled C–C, C–O stretching and C–O–H, C–O–C deformation modes of various oligo- and polysaccharides. The IR bands at about 1020–1035 cm^{-1} and 1040-1055 cm^{-1} indicated C–O–H bending modes associated with amorphous and crystalline starch structure respectively, that were of high intensity in RD 31-NARS noodles than the noodles of RD 31-NARS with 2.5% of XG (Ashwar et al., 2016).

Based on FTIR spectral analysis, the gluten-free noodles with inulin showed the characteristic absorption bands of inulin structure, OH stretch (3300-3400 cm^{-1}) and carbonyl (1600-1680 cm^{-1}), which were prominent as compared to other gluten free noodles. The peaks showed by other gluten free noodles in the same IR region could be due to sugars with same functional groups. IR spectra of inulin showed the most intensive broad band at 1050 cm^{-1} with two shoulders at 940 and 1130 cm^{-1} (Melanie, Susilowati, Iskandar, Lotulung, & Andayani, 2015). FTIR spectra of inulin in the carbohydrate region 900-1200 cm^{-1} showed overlapping broad band with maximum at ~1030 cm^{-1} and stronger absorption at about 940 cm^{-1} (Grube, Bekers, Upite, & Kaminska, 2002). The FTIR spectra of gluten-free noodle with defatted rice bran exhibited absorbance at 3000 and 3300 cm^{-1}, which are assigned to C–H bonds and –OH groups respectively.

3.3.9. Differential scanning calorimetry

Thermal analysis of the noodles was performed by differential scanning calorimetry (Table 8). Generally, the gelatinization temperature of retrograded amylose melts at high temperature ranging from 120 to 170 °C, due to the presence of long-chain double-helical crystallites of amylose (Ma & Boye, 2018). While, the peak temperature of noodles with xanthan gum was the highest than those with xanthan gum and inulin or defatted rice bran indicating that it is not easy to denature at lower temperatures (Li et al., 2016). The peak temperature, onset temperature, and end set temperature of the gluten-free noodles were observed to decrease with the addition of inulin and defatted rice bran, which is related to decrease in gelatinization temperature. Inulin molecules lose their compaction and rigidity with water absorption as water acts as a plasticizer introducing into the inulin chains, increasing the intermolecular distance or free volume and affecting the molecular mobility (Leyva-Porras et al., 2017). Furthermore, high moisture content and presence of non-starch components in rice flour such as protein, ash, fiber and lipids cause a reduction of enthalpy for gelatinization (Thiranusornkij, Thamnarathip, Chandrachai, Kuakpetoon, & Adisakwattana, 2018).

4. Conclusion

The gluten free noodles prepared by resistant rice starch, XG (2.5%), inulin/defatted rice bran (5%) showed low glycemic index and high acceptability by sensory panelists. The addition of defatted rice bran and inulin increased the firmness, cooking time, protein, fiber and ash contents of gluten free noodles. This study contributed that resistant rice starch, XG, defatted rice bran, and inulin can be used as functional ingredients to formulate low glycemic index and nutraceutical gluten free foods.

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CRediT authorship contribution statement

Sujitta Raungrusmee: Data curation, Formal analysis. **Smriti Shrestha:** Formal analysis, Writing - original draft. **Muhammad Bilal Sadiq:** Formal analysis, Conceptualization, Writing - original draft. **Anil Kumar Anal:** Formal analysis, Writing - original draft, Conceptualization.

Declaration of competing interest

The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lwt.2020.109279.

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