Effects of incorporation of black garlic on rheological, textural and sensory properties of rye (Secale cereale L.) flour noodles

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ABSTRACT
The aim of this investigation was to produce black garlic-fortified rye flour noodles with good cooking quality. The color, cooking quality, microstructural, textural and sensory properties of rye flour noodles with and without black garlic pulp (BGP) were investigated. The results indicated that less than 5.0% BGP addition did not affect the sensory properties of rye flour noodles. However, considering color, cooking quality, microstructure and textural properties, noodles fortified 2.0% or 3.0% were the most acceptable products among all prepared noodle samples. Therefore, black garlic can be used as a rich source of varieties of active compounds, i.e. natural antioxidants and dietary fiber, to reinforce new functional noodle products.

Efectos de la adición de ajo negro en las propiedades reológicas, texturales y sensoriales de fideos de harina de centeno (Secale cereale L.)

La presente investigación se propuso producir fideos de harina de centeno enriquecidos con ajo negro que tuvieran buena calidad de cocción. Con este propósito se examinaron el color, la calidad de cocción, la microestructura y las propiedades texturales y sensoriales de fideos de harina de centeno, con y sin pulpa de ajo negro (BGP). Los resultados revelan que la adición de menos de 5.0% de BGP no afectó las propiedades sensoriales de los fideos. Sin embargo, en términos de su color, calidad de cocción, microestructura y propiedades texturales, los fideos enriquecidos al 2.0% o 3.0% fueron los productos más aceptables de todas las muestras de fideos preparadas. Por lo tanto, se concluye que el ajo negro puede utilizarse como una fuente rica en diversos compuestos activos, esto es, antioxidantes naturales y fibra dietética, para enriquecer nuevos productos funcionales de fideos.

Introduction
Noodles are widely consumed in Asian countries, accounting for an average of 20–50% of the total consumption of wheat flour (Ahmed, Qazi, & Jamal, 2015). Traditional noodles are commonly made from wheat (\textit{T. aestivum}) flour, water and/or salt by mixing, sheeting and cutting of dough (Pu et al., 2017; Redant, Buggenhout, Brijs, & Delcour, 2017). Nowadays, noodle has become a global food due to its convenient cooking, nutritional benefits, and delicious taste (Ahmed et al., 2015; Pu et al., 2017). In addition to the utilization of common wheat flour, other grains (rice, buckwheat, oat, barley, etc.) and starches derived from potato, sweet potato and pulses have been used to prepare a variety of noodles. Besides, noodles with an appropriate addition of natural, healthy and nutritional substances will provide an improved consumer acceptability and preference, regarding as an effective way to develop health-benefit products for consumers (Ahmed et al., 2015; Pu et al., 2017).

Rye belonging to the genus \textit{Secale L.} is an important cereal for human. Rye (\textit{Secale cereale L.}) is primarily grown in Eastern, Central and Northern Europe (Hillman, 1978). In Europe, rye is considered to be the second most common grain crop used for bread making (Redant et al., 2017). The cultivated high-quality rye is considered to be an idea raw material for developing flour products, such as noodles, bread and dumplings, because of its high protein, content and excellent nutritive value, particularly the high dietary fiber content (Comino, Collins, Lahnstein, & Gidley, 2016; Kruger, Hatcher, & Anderson, 1998). Preliminary findings indicated that the addition of rye flour generally causes the noodles to dim (Kruger et al., 1998). This may be due to that storage proteins in rye are partially homologous to those of wheat, but they lack the ability to form a three-dimensional viscoelastic protein network (Redant et al., 2017). Several studies reported that the incorporation of natural products with functional compounds like antioxidants or soluble dietary fiber could be an effective way for developing healthy and high-quality noodles (Choo & Aziz, 2010; Kazemi, Karim, Mirhosseini, Hamid, & Tamnak, 2016).

Black garlic (\textit{Allium sativum}) is produced by heating fresh garlic under controlled temperature and humidity for several weeks and is used as a healthy food and herbal supplement throughout the world (Zhang et al., 2015). Many studies demonstrated that black garlic has a wide range of health benefits, including antioxidant, antitumor, anti-allergic, etc.
(Bae, Cho, Won, Lee, & Park, 2012). These health properties of black garlic are closely related to its bioactive compounds, which may be formed during heat treatment (Kim, Kang, & Gweon, 2013). It has reported that black garlic contained an increased amount of antioxidants compared to raw garlic (Ban et al., 2011). Besides, black garlic is rich in dietary fiber, especially soluble dietary fiber, that possesses important functional properties of preventing constipation and regulating intestinal flora, as well as changing the rheological, textural and sensory properties of flour-based products (Qian, Rui, Tao, & Min, 2016). Therefore, there is a possibility to fortify the rye noodles with black garlic which contains the natural antioxidants and dietary fiber to induce healthier features of noodle products.

The objective of this study was to process new rye flour noodles fortified with black garlic pulp (BGP) with good cooking quality. Effects of BGP on the color, cooking, textural, microstructural, and sensory properties of rye flour noodles were investigated. Besides, the rheological and microstructural analysis of rye flour doughs fortified with BGP were also conducted.

Material and methods

Materials

Rye (Secale cereale L.) flour was obtained from Jing Hong Yuan Modern Agricultural Science and Technology Company (Jing Country, Hebei Province, China). Black garlic was provided by Dalian Liang Yun Co., Ltd (Dalian city, Liaoning Province, China). Table 1 shows the chemical composition of rye flour and black garlic AOAC (2000). The K-RINTDF assay kits were purchased from Megazyme (Co. Wicklow, Ireland). All other chemicals and reagents were of analytical grade.

Noodle formulation

BGP was prepared by milling 50 g mixtures of black garlic cloves and deionized water for 60 s using a model JYL-C012 refiner (Joyoung Co., Ltd, Jina, China) at a power of 250 W and a frequency of 50 Hz. The water content of BGP was set to 61%. The average diameter of milled BGP was 66.88 μm, as determined using a BT-9300S laser particle size analyser (Dandong Bettersize Instruments Ltd., China).

The base ingredients with different concentrations of BGP were prepared for the noodles, in order to investigate the effects of adding BGP on the quality of noodles. The BGP-fortified rye flour noodles were prepared according to the procedure reported in previous literatures (Bharath Kumar & Prabhasankar, 2015; Gatade & Sahoo, 2015a) with some modifications. Briefly, 300 g of rye flour, BGP (0%, 1%, 2%, 3%, 4% and 5% of rye flour dry basis) and distilled water were mixed to form the firm dough using HM740 noodle mixer (Guangdong, China). The total addition amount of distilled water was 38% of rye flour dry basis. The dough was rested for 30 min and then sheeted to 0.8 mm thickness in dough sheeter. The dough piece was cut into noodles with a width of 1.93 mm and a length of 20 cm in a model FKM-200 automatic noodle cutter (Zhejiang, China). The noodles were placed on a drying rack and dried in a cabinet dryer at 55°C for 2 h. The dried noodles were cooled down and package sealed until further analysis (Figure 1(a)).

Color measurement

The color of dried noodles was determined with Lab 3 nh (2° viewing angle and 2 nm slit width) equipped with a D65 light source. The noodle samples were placed in a transparent glass Petri dish and put on the slit opening, measuring the surface color in triplicate. The \( L^* \), \( a^* \) and \( b^* \) value were obtained, and they represent lightness, redness, yellowness for positive, and darkness, greenness, blueness for negative values, respectively (Hutchings, 1999). A pasta color index (PCI) was also calculated with the above \( L^* \) and \( b^* \) values using the following equation (Ugarčić-Hrdić, Perić, Strelec, & Koceva, 1999).

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PCI = \sqrt{L^* + b^*}
\] (1)

Cooking quality analysis

The best cooking time and cooking loss of noodles were determined modifying the AACC methods 66-50 (2000). Ten grams of dried noodle samples were added to a 300 mL of boiling water and a piece of noodle, size 0.8 cm × 20 cm, with a thickness of 2 mm, was taken out every 15 s, pressing with two glass slides until the white hardcore of noodles disappeared. The best cooking time was then recorded. After the noodles were optimally cooked, the cooking water was evaporated at 125°C to constant weight, and the percentage of the weight of evaporation residue based on the weight of uncooked dried noodles was reported as the cooking loss. Each test was performed in triplicate. The water uptake was determined by weighing the mass difference of the cooked and dried noodles (Gatade & Sahoo, 2015b).

Rheological analysis of dough

To measure the effect of different BGP addition on the rheological properties of dough, a frequency sweep test was carried out on the dough using a Haake Mars-III rheometer (Thermo Fisher Scientific Inc., Germany) equipped with a 20 mm diameter steel plate gapped by 1 mm. The edges of the steel plate were sealed with a low-viscosity mineral oil at the concentration of 0.84 g/mL (Sigma-Aldrich, St Louis, MO, USA) to minimize water loss. The sweep procedure was conducted from 0.1 to 100 rad/s, where the linear viscoelastic region was identified by a preliminary strain sweep test at 1 Hz and 25°C. The storage modulus (\( G' \)) and loss modulus (\( G'' \)) were recorded and the loss factor (\( \tan \delta \)) was reported as \( G''/G' \) (Qian et al., 2016).

Table 1. The chemical composition of rye flour and black garlic.

| Sample          | Moisture content (%) | Fat (%) | Protein (%) | Ash (%) | Carbohydrates (%) | Starch (%) | Total dietary fiber (%) |
|-----------------|----------------------|---------|-------------|---------|-------------------|------------|------------------------|
| Rye flour       | 11.25 ± 0.12         | 1.21 ± 0.01 | 12.67 ± 0.07 | 0.64 ± 0.02 | 74.24 ± 0.17 | 53.86 ± 0.65 | 1.10 ± 0.05            |
| Black garlic    | 48.57 ± 0.36         | 1.01 ± 0.15 | 10.90 ± 0.17 | 2.35 ± 0.06 | 37.14 ± 0.12 | –          | 10.49 ± 0.27            |
Texture measurement

The texture profile analyses of noodles were determined using a TA.XT plus texture analyser (Stable Micro System, England) equipped with a P36 probe, using 2.0 mm/s of pre-test speed, 1.0 mm/s of test speed, 1.0 mm/s of post-test speed, 70% of compression degree, automatic trigger type and 5.0 g of trigger force. The firmness, springiness, cohesiveness, adhesiveness, chewiness and recovery were analyzed by the Texture Expert for Windows software version 1.20 (Stable Micro Systems).

For tensile test, the tensile force (g) and breaking distance (cm) were also measured using the TA.XT Plus texture analyser equipped with a A-KIE probe. Strips of gluten films (0.8 cm × 0.2 cm × 6 cm) were mounted in the tensile grips. Using 2.0 mm/s of pre-test speed, 3.0 mm/s of test speed, 10.0 mm/s of post-test speed, 6.0 cm of distance, automatic trigger type, 5.0 g of trigger force. The tensile force and breaking distance were determined from stress-strain curve (Antoniou, Liu, Majeed, & Zhong, 2015).

Scanning electronic microscopy

Noodle samples were fixed and sputter-coated with a thin layer of gold using a sputter coater (Hummer XP, Anatech, CA, USA). SEM images of noodle samples were performed on a Hitachi SU-1510 SEM system (Pleasanton, CA, USA) at a beam accelerating voltage of 5 kV. The surface and cross-section morphologies of noodle samples were imaged with magnification of ×500.

Sensory evaluation

The organoleptic properties of dried noodles were evaluated as described by 10 panelists proficient in noodle characteristics. Rye flour noodles treated with 0%, 1.0%, 2.0%, 3.0%, 4.0%, and 5.0% BGP were prepared at the best cooking time. The panelists evaluated the organoleptic properties toward firmness, chewiness, springiness and overall acceptability of cooked noodles with a 9-point descriptive scale with score ‘1’ = ‘dislike extremely’, ‘5’ = ‘neither like nor dislike’, and ‘9’ = ‘like extremely’.

Figure 1. (A) Production of black garlic pulp (BGP)-fortified rye flour noodles, and (B) the cooked rye flour noodles with different BGP concentrations.

Figura 1. (A) Producción de fideos de harina de centeno enriquecidos con pulpa de ajo negro (BGP) y (B) fideos de harina de centeno cocidos con distintas concentraciones de BGP.
Statistical analysis

Results of color measurement, cooking quality analysis, texture measurement and sensory evaluation were expressed as the mean values ± standard deviation (SD) from at least three independent experiments. The data were analyzed by one-way ANOVA using OriginPro 8 SR4 (version 8.0, Northampton, USA). Differences were considered statistically significant at P < 0.05.

Results and discussion

Effect of BGP on the color of rye flour noodles

The addition of 2.0–5.0% BGP to the rye flour noodles led to a significant change of color from bright yellow to yellowish brown (Figure 1(b)). Table 2 shows the color values L*, a*, and b* of rye flour noodles with and without BGP. In general, consumers prefer noodles with a bright yellow color (Cavazza et al., 2013). Nevertheless, the L* values of rye flour noodles negatively decreased by increasing the concentration of BGP, the a* values positively increased, and the b* values had no considerable change. Regarding PCI values, BGP-fortified rye flour noodles showed significantly lower values (P < 0.05) compared to pure rye flour noodles. The difference between maximum and minimum PCI values was compared with the maximum difference of L* values, but showed significantly higher values than the maximum difference of b* values. It was clear that incorporation of BGP notably affected the color of rye flour noodle, and turned it color to darker brown. Sang, Cho, Yong, Lee, and Park (2012) reported that the representative brown color was formed by non-enzymatic browning during the production of black garlic, resulting in the L* and b* values of black garlic radically diminished, whereas a* values increased during the aging period (Choi, Cha, & Lee, 2014). Thus, the lightness of rye flour noodles decreased, whereas the redness increased with the increasing of BGP concentration.

Effect of BGP on the cooking properties of rye flour noodles

As shown in Table 2, the cooking loss of rye flour noodle first decreased (P < 0.05) from 7.39% to 5.86% in the concentration range of 0–3.0% BGP, and then increased to 7.24% when 5.0% BGP was added to the rye flour noodle formulations. According to Dick and Youngs (1988), cooking loss of 7.0–8.0% is acceptable for dried pasta. The lowest cooking loss for rye flour noodle was achieved in the presence of 2.0% or 3.0% BGP with no significant difference (P > 0.05). It is rare to make noodles or other flour products with rye flour alone, which is usually combined with wheat flour or/and other cereal flours, such as buckwheat flour and barley flour (Hirano, Yoshida, Asahina, & Tanaka, 2017), because rye flour does not contain gluten proteins like in wheat flour, and thus cannot form a viscoelastic protein network structure itself (Redant et al., 2017). Therefore, soluble parts of starch and other soluble small particles in rye flour noodles are released from the noodle surface into the water, resulting in a loss during cooking (Sun-Waterhouse, Jin, & Waterhouse, 2013). The addition of appropriate amounts of BGP could help to strengthen the gluten network of rye flour dough through its rich Maillard reaction products and garlic polysaccharide degradation compounds (mainly fructose and oligo-fructose) (Zhang et al., 2015) to interact with the proteins in rye flour dough. Nevertheless, an excessive addition of BGP dilute the gluten network in noodles (Kazemi et al., 2016) and weaken the structure of the gluten network to cause exposure of starch granules to some degree, thus resulting in an increase of cooking loss compared with that of 2.0% or 3.0% BGP-fortified rye flour noodle.

The cooking time of BGP-fortified rye flour noodles decreased with increasing the BGP concentration. The reduction of optimum cooking time could be attributed to the presence of BGP which facilitates the imigration of water. On one hand, Oh, Seib, Deyoe, and Ward (1985) reported that the cooking time of noodles increased linearly with the protein content in flour. The BGP-diluted rye flour proteins and starches are easier hydrated, leading to a shorter cooking time. On the other hand, the high water absorption capacity of fructose and oligo-fructose in BGP might cause the penetration of water to inner parts of noodles (Franck, 2002). Furthermore, the content of dietary fiber in was as high as 10.47%. With the increase of the amount of BGP, the water absorption capacity of noodles increased, leading to the reduction of the best cooking time. However, adding more than 3% of BGP might dilute the gluten protein and compete with the moisture in the dough, thereby weakening the formation of the gluten protein network, leaving the starch particles exposed, and leading to the cooking loss of noodles (Foschia, Peressini, Sensidoni, Brennan, & Brennan, 2015).

Rheological analysis of rye flour doughs fortified with BGP

The storage modulus (G’), loss modulus (G”) and the loss factor (tanδ) were analyzed according to the results of the oscillatory test (Figure 2). The frequency dependency of G’, G” and tanδ indicated the viscoelastic behavior of rye flour doughs fortified with BGP. Incorporating 3.0% BGP has the lowest storage and loss modulus, which might be due to
dilution of gluten protein and competition for protein binding to water molecules (Wang, Hamer, Vliet, & Oudgenoeg, 2002). However, increasing the BGP concentration between 3.0% and 5.0% enhances the elastic and viscous modulus. In consistent with the result of tensile test (Table 3), the excess BGP addition may produce an increase of dough extension resistance, thereby increasing gluten hardness. According to Rebellato et al. (2017), the rheological properties of the dough were influenced by different iron compounds and the sample fortified with NaFeEDTA showed a significant increase of resistance to extension, after 45 min. Therefore, the increasing trend of minerals content along with the BGP concentration might affect the rheological properties of doughs, indicating a competitive interaction for the absorption of minerals in whole wheat roll breads. While the study of Gujral, Park, and Baik (2008) showed that although the added ash changed the pasting properties of doughs, it exhibited no significant effect on cooked noodle texture. Furthermore, the $\tan \delta$ notably decreased with the addition of more than 3.0%.

Table 3. Textural and sensory properties of rye flour noodles with different concentrations of black garlic pulp (BGP).

| Sample         | 0% BGP | 1.0% BGP | 2.0% BGP | 3.0% BGP | 4.0% BGP | 5.0% BGP |
|----------------|--------|----------|----------|----------|----------|----------|
| **Texture profile analysis** |        |          |          |          |          |          |
| Firmness (N)   | 46.412 ± 0.276$^a$ | 48.815 ± 0.592$^c$ | 54.716 ± 0.795$^a$ | 45.393 ± 0.187$^a$ | 48.498 ± 0.580$^c$ | 50.550 ± 0.119$^a$ |
| Springiness    | 0.894 ± 0.014$^a$ | 0.918 ± 0.051$^a$ | 0.915 ± 0.069$^a$ | 0.923 ± 0.013$^a$ | 0.912 ± 0.008$^a$ | 0.935 ± 0.046$^a$ |
| Cohesiveness   | 0.707 ± 0.031$^{ab}$ | 0.710 ± 0.002$^{ab}$ | 0.718 ± 0.004$^{ab}$ | 0.716 ± 0.015$^{ab}$ | 0.703 ± 0.025$^{ab}$ | 0.685 ± 0.009$^{ab}$ |
| Adhesiveness   | 31.662 ± 0.702$^d$ | 34.683 ± 0.459$^b$ | 39.278 ± 0.477$^a$ | 32.480 ± 0.815$^c$ | 34.096 ± 1.595$^{bc}$ | 34.629 ± 0.903$^b$ |
| Chewiness      | 35.646 ± 0.437$^a$ | 31.845 ± 0.031$^{bc}$ | 35.933 ± 0.796$^a$ | 29.977 ± 0.936$^d$ | 31.424 ± 0.783$^a$ | 33.008 ± 0.292$^b$ |
| Recovery       | 0.348 ± 0.017$^a$ | 0.347 ± 0.004$^a$ | 0.363 ± 0.012$^a$ | 0.354 ± 0.007$^a$ | 0.341 ± 0.019$^a$ | 0.318 ± 0.009$^b$ |
| **Tensile test** |        |          |          |          |          |          |
| Tensile force (g) | 42.33 ± 0.51$^a$ | 36.93 ± 0.73$^b$ | 34.22 ± 0.72$^b$ | 30.03 ± 0.76$^c$ | 33.10 ± 0.56$^e$ | 37.35 ± 0.44$^{ab}$ |
| Breaking distance (cm) | 13.94 ± 0.45$^a$ | 12.80 ± 0.50$^b$ | 13.97 ± 0.67$^a$ | 12.11 ± 0.50$^a$ | 12.35 ± 0.60$^e$ | 14.01 ± 0.07$^{ab}$ |
| **Sensory evaluation** |        |          |          |          |          |          |
| Firmness       | 6.83 ± 1.17$^a$ | 6.50 ± 1.22$^a$ | 6.17 ± 0.98$^a$ | 6.83 ± 0.98$^a$ | 6.50 ± 1.38$^a$ | 7.17 ± 0.75$^a$ |
| Chewiness      | 7.17 ± 0.98$^b$ | 6.50 ± 1.22$^a$ | 6.50 ± 0.84$^a$ | 7.33 ± 0.82$^b$ | 6.50 ± 1.38$^a$ | 6.83 ± 0.98$^a$ |
| Springiness    | 6.67 ± 1.37$^a$ | 6.83 ± 0.98$^a$ | 6.00 ± 1.41$^a$ | 6.67 ± 0.82$^a$ | 7.00 ± 1.10$^a$ | 6.67 ± 1.03$^a$ |
| Overall acceptability | 6.33 ± 1.37$^a$ | 6.33 ± 1.37$^a$ | 6.00 ± 1.55$^a$ | 7.17 ± 0.75$^a$ | 7.00 ± 1.10$^a$ | 7.00 ± 1.10$^a$ |

Note: Data are expressed as mean ± standard deviation. Different letters indicate significant differences at $P < 0.05$ in the same row.

Nota: Los datos se presentan como medias ± desviación estándar. Las distintas letras en la misma fila indican diferencias significativas a $P < 0.05$. 

Figure 2. Storage modulus, $G'$ (A), loss modulus, $G''$ (B), and the loss factor, $\tan \delta$ (C) of rye dough with different addition amounts of black garlic pulp (BGP) studied by rheological analysis.

Figura 2. Módulos de almacenamiento, $G'$ (A), módulos de pérdida, $G''$ (B), y el factor de pérdida, $\tan \delta$ (C) de la masa de centeno adicionada con distintas cantidades de pulpa de ajo negro (BGP) estudiado mediante análisis reológico.
BGP, which also proposed that excess addition of BGP diluted the network of gluten compared with that of pure gluten.

**Morphologies of rye flour noodles fortified with BGP**

Scanning electron microscopy (Figure 3) showed that starch granules were interspersed in the gluten network and exposed onto the dough surface of the control noodles (Li et al., 2012; Luo, Guo, & Zhu, 2015). The dough tended to be more homogeneous and the number of exposed starch granules was lower when a suitable amount of 2.0% BGP was added. According to Zhang et al. (2015), the polysaccharide content in the black garlic decreased gradually from 98.4% to 29.4%, whereas the monosaccharide and oligosaccharide content increased from 1.6% to 70.6%. The gluten proteins interacted with these saccharides in BGP and embed the starch granules, thereby resulting in a more continuous structure in noodles with an addition of 2.0% BGP. However, the addition of 3.0% BGP diluted the gluten network and the saccharides in black garlic competed with gluten for water absorption, leading to the weakening of gluten network. Several gaps were also observed and starch granules were exposed more, especially in dough with 4.0% and 5.0% BGP.

**Effect of BGP on the textural and sensory properties of rye flour noodles**

The textural and sensory properties of BGP-fortified rye flour noodles are shown in Table 3. The results of textural properties showed that the firmness, adhesiveness and chewiness of noodles were remarkably influenced by the addition of BGP (P < 0.05), while the springiness, cohesiveness and recovery were not significantly changed with the addition of BGP (P > 0.05). Consistent with the result of SEM, 2.0% BGP-fortified rye flour noodle has the maximum firmness, adhesiveness and recovery. When increasing the concentration of BGP from 3.0% to 5.0%, the firmness and adhesiveness changed higher, but the recovery became lower due to the dilution of gluten network. Furthermore, BGP-fortified rye flour noodles have smaller tensile force than that of the control noodles; which indicates the reduction of extensibility resistance. In term of breaking distance, 3.0% BGP-fortified rye flour noodle has a minimum value of breaking distance, representing the reduction of viscosity of dough, consistent with its lowest elastic and viscous modules in rheological analysis. Although the breaking distance increased when more than 3.0% of BGP was added in rye flour noodles, the gluten network was diluted and the cooking quality was reduced. In addition, the sensory evaluation result showed that the firmness, chewiness, springiness and overall acceptability showed no significant difference among noodles. It may be attributed to that the protein content in rye flour used is relatively high and thus the gluten network strength has not been seriously affected. Therefore, a black garlic-containing noodle was successfully produced. Considering the color and cooking quality, adding 2.0% or 3.0% BGP is suitable for rye flour noodles.

**Conclusions**

Black garlic, a processed product of fresh garlic, was incorporated into rye flour noodles for developing healthy noodles. The present study showed that less than 5.0% BGP addition had no significant influence on the sensory properties of rye flour noodles. Comprehensively considering color, cooking quality, microstructure, and textural properties, the 2.0% or 3.0% BGP-fortified rye flour noodles were the most acceptable products among all prepared noodle samples. Therefore, black garlic can be used as a rich source of natural antioxidants and dietary fiber for the fortification of a new functional noodle product.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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