Quality of High-Fiber Pasta Supplemented with Watermelon Rind Powder with Different Particle Sizes

Running head: Pasta with Watermelon Rind Powder

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SUMMARY

Research background. Watermelon rind, a by-product of watermelon juice processing, contains high amounts of dietary fiber and phenolics with antioxidant capacity. The use of agro-industrial by-products would improve the economic benefits as well as reduce the environmental emissions. The goal of this research was to examine the impacts of particle size of watermelon rind powder on the quality of high-fiber pasta.

Experiment approach. Three samples of watermelon rind powder passed through three sieves with aperture sizes of 400, 210, and 149 μm were determined for their nutritional, physical and physico-chemical quality. Wheat durum semolina and watermelon rind powder (90:10 by mass) were then mixed and used to make pasta. Nutritional, textural, and cooking quality, sensory acceptability, in vitro glycemic index, and antioxidant bioaccessibility of high-fiber pasta added with watermelon rind powder with different particle size means were evaluated and compared.
Results and conclusions. When the sieve aperture size was reduced from 400 to 149 µm, the soluble dietary fiber and total phenolic contents of watermelon rind powder were enhanced by 35 and 15%, respectively while its insoluble dietary fiber content was decreased by 21%. Decrease in sieve aperture size from 410 to 149 µm for watermelon rind powder reduced phenolic bioaccessibility of the fortified pasta from 63 to 57% but enhanced its predicted glycemic index from 50 to 69; such decrease also lowered the pasta hardness by 13% but improved its elongation rate and tensile strength by 13 and 40%, respectively. The finer the watermelon rind powder particles, the longer the optimal cooking time, the greater the water absorption index, and the less the cooking loss of the supplemented pasta. Consumers did not notice any significant difference in the overall acceptability among all pasta samples.

Novelty and scientific contribution. Particle size of watermelon rind powder had great impacts on nutritional, textural and cooking quality of the fortified pasta. Particularly, the predicted glycemic index and antioxidant bioaccessibility of high-fiber pasta were significantly affected by the particle size of dietary fiber material used in the recipe.

Keywords: antioxidant activity; bioaccessibility; dietary fiber; pasta; watermelon rind

INTRODUCTION

The pasta industry has been developed to supply a staple food for people in the world owing to its low cost and simplicity of preparation (1). Pasta is high in carbohydrates, the major compound of which is starch while fiber content is very low (0.9–1.9 g/100 g pasta) (1). An adequate dietary fiber intake (about 35 g/day for adults) has been associated with a decrease in many health concerns including digestion disorders, diabetes, colon cancer, and coronary heart diseases (2,3). Besides, pasta is poor in bioactive compounds such as antioxidants (4) which are responsible for lowering risks of chronic illness development and aging, including obesity, cardiovascular diseases, and various types of cancer (5). From the last decade, functionalization of pasta products has attracted great attention (6). The common source of dietary fiber and antioxidants for pasta formulation is whole grain flour, which is ground from whole, unprocessed cereal grains, including wheat, oat, barley, or rice flour (7). Other plant powders with high fiber and antioxidant content such as fruits, vegetables (4), herb seeds (1), or flowers (8) are also added to pasta recipe. Another option to augment the fiber and antioxidant content of pasta is to replace dough water with fruit juice or fruit and vegetable
puree (4). From the past decade, agro-industrial by-products, especially fruit by-products have been added to the pasta formulation to enhance its dietary fiber and antioxidant contents (9).

Watermelon, a Cucurbitaceae family member, is an appreciated fruit that grows in tropical and subtropical climes ascribed to its high nutritional value (10). In 2021, the productivity of watermelon fruit in the world and in Vietnam is about 101.6 and 1.5 million tons, respectively (11). Rind, which accounts for 30-41% of the overall mass of watermelon fruit, is primary solid waste released from watermelon juice processing (10). Commonly, this by-product is utilized in the production of animal feed or fertilizer. However, watermelon rind (WR) contains high amounts of total dietary fiber, protein, and minerals (10). WR is also reported to have high antioxidant activity owing to the occurrence of phenolics, L-citrulline, terpenoids, saponins and alkaloids (12). Among them, phenolic compounds, especially 4-hydroxybenzoic acid and vanillin, are the main antioxidants of WR (10,12,13). WR is subjected to extraction of different bioactive such as citrulline, pectin, and polysaccharide with bioactivity (13). In addition, the direct use of WR in the formulation of different food products such as cookies, bread and noodle (13) is reported to enhance their dietary fiber and phenolic contents.

Textural profile of pasta is influenced by the particle size of the material flour (9). In addition, the particle size of raw materials also affects the bioaccessibility of nutrients as well as antioxidants of food products (14). Nevertheless, the impacts of particle size of WR powder on the quality of high-fiber pasta has not been reported in the literature. The objective of this study was to evaluate the effects of particle size of WR powder on nutritional, textural and cooking quality, and overall acceptability of high-fiber pasta. Furthermore, the glycemic index and bioaccessibility of phenolic compounds of the obtained product samples were also evaluated by an in vitro test.

MATERIALS AND METHODS

Materials

Watermelon (Citrullus lanatus (Thunb.) Matsum. & Nakai) fruits were collected from a local farm (Long An province, Vietnam). At the laboratory, the fruit exocarp was separated and the outer green peel was manually removed; the white rind was subsequently cut into 2 cm×5 cm×0.2 cm pieces, dried at 50 °C to achieve 12 % moisture content. About 200 g dried watermelon rind was added to a hammer mill (Binh Minh Ltd., Ha Noi, Vietnam), in which eighteen swinging hammers are fixed to the rotor; the rotation rate was 2,400 rpm and the milling time was 2 min for each batch. The obtained watermelon rind powder from all milling
batches was well mixed and divided into three parts. Each part was screened through a sieve. In this research, 40, 70, and 100-mesh sieves with apertures of 400, 210, and 149 μm, respectively were used. The obtained WR powder fractions were vacuum-packed in polyethylene bags, stored at 4 °C and used for experimentation within 4 weeks. Durum wheat semolina was provided by Vietnam Wheat Milling Co., Ltd. Sodium chloride was procured from Vietnam Southern Salt Group.

Enzyme preparations including Termamyl®SC with alpha-amylase activity, Dextrozyme®GA with glucoamylase activity, and Alcalase®2.5 L with protease activity were purchased from Novozymes (Bagsværd, Denmark) and used for fiber determination. Salivary α-amylase, pepsin from porcine gastric mucosa, pancreatic from porcine pancreas (8×USP specifications) and bile salts were bought from Merck KGaA (Darmstadt, Germany) and used for in vitro experiments. Chemicals of analytical grade including Folin–Ciocalteu reagent, 2,2-diphenyl-1-picrylhydrazyl (DPPH), gallic acid (GA), Trolox, 2,4,6-tri(2-pyridyl)-s-triazine (TPTZ) and 3,5-dinitrosalicylic acid (DNS) were provided from Merck KGaA (Darmstadt, Germany).

Pasta making in the laboratory

Four pasta samples were prepared: control sample P (without WR addition) and three WR-added samples P400, P210, and P149 in which 10 % durum wheat semolina was replaced by WR powder samples sifted through 400, 210 and 149 μm-aperture sieves, respectively. The pasta making process is referenced by Nguyen et al. (3) with slight modification. About 150 g mixture of durum semolina and WR powder, and table salt (0.5 % (m/m) on the blend dry mass) were mixed in a dough mixer (Model 5K5SS-Heavy Duty KitchenAid, Whirlpool Co., Michigan, USA) for 5 min using a flat beater. About 70 mL distilled water at 42 °C was then added and mixed at 120 rpm for 2 min; the flat beater was replaced with a dough hook and the mixture was kneaded at 120 rpm for another 20 min to make a pasta dough with 39 % moisture content. The acquired dough was subsequently fed to an extruder (Model HR2365/05, Philips Co., Eindhoven, Netherlands) with die size of 4 mm×2 mm and extrusion pressure of 720 kgf/cm². The extruded pasta strands were dried at 50 °C for 5 h in a convective dryer. The dried pasta was kept in polyethylene pouches at 4 °C until analysis.

Nutritional quality

Moisture content was determined by drying at 105 °C to constant mass, using a moisture analyzer (Model ML-50, A&D Co., Tokyo, Japan). Total ash was estimated by
incineration at 600 °C, using a muffle furnace (Model EF11/8B-Lenton Furnaces, Carbolite Gero Ltd, Sheffield, UK), following to the Association of Official Analytical Chemists AOAC 942.05 method (15). Total protein was quantified by Kjeldahl digestion using AOAC 979.09 method and the protein-nitrogen conversion factor of 5.7 (15). Total lipid was measured by Soxhlet extraction following AOAC 948.22 method (15). Starch was quantified using AOAC 996.11 method (15). Reducing sugars were evaluated by a spectrophotometric method using DNS reagent (16). Total sugar was assessed by AOAC 945.66 method using Fehling reagent (15). Insoluble dietary fiber (IDF), soluble dietary fiber (SDF) and total dietary fiber (TDF) were measured by enzymatic-gravimetric principle following AOAC 991.42, 993.19 and 991.43 methods (15), respectively. Pectin was determined by extraction and subsequent precipitation with ethanol according to the procedure reported by Petkowicz et al. (17).

**Phenolic compounds and antioxidant activity**

Phenolics were extracted with 60 % (V/V) ethanol; the extraction conditions were described elsewhere (3). The extract was used for evaluation of total phenolic content (TPC), total flavonoid content (TFC) and total anthocyanin content (TAC) as well as antioxidant activities. Total phenolics were evaluated using Folin-Ciocalteu reagent and spectrophotometric method (3) and presented in mg gallic acid equivalent (GAE) per kg dry mass. Total flavonoids were determined by spectrophotometric method using the procedure previously reported (18) and expressed in mg quercetin equivalent (QE) per kg dry mass. Total anthocyanins were measured by pH differential method and shown in mg cyanidin-3-glucoside equivalent (CGE) per kg dry mass (18).

Ferric reducing antioxidant power (FRAP) and DPPH radical scavenging activity were determined according to the procedures described elsewhere (3) and presented as µmol Trolox equivalent per kg dry mass of the sample (µmol TE/kg DM).

**Physical properties**

The particle size of durum wheat semolina and WR powder was measured using a laser particle size analyzer (Model MAZ3000, Malvern Instruments Ltd, Worcestershire, UK). The results were expressed by particle size range, mean value ($D_{[4,3]}$), span value and specific surface area ($A_m$) (3). Bulk density was measured according to procedure described elsewhere (19).
Water holding capacity (WHC) was determined according to the procedure described by Mai et al. (2). Water solubility index (WSI) and swelling capacity (SC) were analyzed according to the procedure reported by Ming et al. (19).

Instrumental color was measured using a chromameter (Model CCM-3700A, Konica Minolta Co., Osaka, Japan) and expressed as $L^*$ (lightness), $a^*$ (redness), and $b^*$ (yellowness) values. Total color difference ($\Delta E$) was calculated by formula previously described (3).

Cooking quality

The cooking quality of pasta including optimal cooking time (OCT), cooking loss (CL), water absorption index (WAI), and swelling index (SI) was determined following the procedure reported by Nguyen et al. (3).

Textural properties of cooked pasta

Textural properties of cooked pasta were evaluated by a texture analyzer (Model TA-XT plusC, Stable Micro Systems Co., Godalming, Surrey, UK) with Exponent Connect Lite Software, v. 6.1.7 (20). Hardness, adhesiveness, tensile strength (MPa) and elongation rate (%) were recorded according to the measurement described by Nguyen et al. (3).

In vitro digestion of cooked pasta

The in vitro digestion of cooked pasta was carried out according to the procedure given by Lucas-González et al. (21). Bioaccessibility index of total phenolics (%) was calculated by a formula described elsewhere (21).

The in vitro glycemic index for all pasta samples were estimated following to the procedure described by Nguyen et al. (3).

Overall acceptability

Sixty non-smokers and untrained panelists (40 men and 20 women) aged from 18 to 28 were selected from students and staff of Ho Chi Minh City University of Technology (Vietnam). They were recruited for the frequency of pasta use (at least once a week). All pasta samples were assigned 3-digit codes and served at a time in a randomized sequence. Water was supplied between samples for mouth cleansing. A 9-point hedonic scale ranging from point 1 (extremely dislike) to point 9 (extremely like) was used for overall acceptability.

Statistical analysis
Each pasta sample was prepared in triplicate. The results were shown as mean ± standard deviation. One-way analysis of variance and Tukey's post-hoc test (significance level set at p<0.05) were applied to distinguish the significant difference between mean values using Statgraphics Centurion program, v. 18.1.12 (22).

RESULTS AND DISCUSSION

Nutritional quality, antioxidant activity, and physical properties of watermelon rind powder and wheat semolina

Table 1 shows nutritional quality, antioxidant activity and physical properties of WR powder and semolina used in this study. When the sieves with smaller apertures were used, the obtained WR powder sample had a narrower range of particle size distribution, its mean value of particle size was lower while its specific surface area and bulk density were greater; the uniformity of particle size was significantly improved. The particle size distribution of durum wheat semolina was considerably wider than that of all WR powder samples. The finer the particle of fiber material, the better the dispersion in food system (23).

The TDF content of WR powder samples was much greater than that of durum wheat semolina. The exocarp of watermelon fruit contains dense fibrous tissue (24) to protect the flesh. Different fiber compounds are identified in WR such as cellulose, hemicellulose, lignin and pectin; among them, pectin is a predominant soluble fiber (13). When the sieve pore size was reduced from 400 to 149 µm, the TDF and IDF contents of WR powder were lowered by 7 and 21%, respectively, while its SDF and pectin contents were raised by 24 and 35%, respectively. It is reported that fiber components of plant materials are hard to be milled into fine particles because of their high surface energy (25,26). As a result, the large particles of milling product contained more dietary fiber than the small ones. Similar change in dietary fiber content of pulverized potato peel was also reported when its particle size mean was reduced (27). Decrease in aperture size of the sieve from 400 to 149 µm resulted in a reduced IDF/SDF ratio of WR powder but its value was always less than that of durum wheat semolina. Additionally, the starch content of three WR powder samples was not significantly different. Meanwhile, the durum wheat semolina contained noticeably more starch than the WR while the protein content of durum wheat semolina was similar to or slightly less than that of WR. When the sieve opening size decreased from 400 to
149 µm, the lipid and ash content of WR powder was moderately reduced. The ash content of WR was 22.8-25.6 times higher than that of durum wheat semolina. Previous study shows that WR contains various minerals such as potassium, calcium, magnesium, and iron, which are essential for the human diet (13). WR was therefore a source of dietary fiber and different nutrients for development of high-fiber foods.

### Table 1

The antioxidant contents and activities of WR powder were much greater than those of semolina. The smaller the aperture size of the sieve, the higher the TPC and TFC of WR powder. According to Bender et al. (28), fine grinding could break down the bonds between phenolics and fibers, resulting in a better extraction of phenolics from plant materials. An increment in TPC was also observed with a decrement in particle size mean of peel powder from pomegranate (29) and apple fruits (30). However, the TAC of WR powder dropped marginally when the sieve opening size decreased. When the sieve aperture size was decreased from 400 to 149 µm, the antioxidant capacity of WR powder measured by DPPH and FRAP assays increased by 28 and 78%, respectively. Among the bioactive compounds quantified in the study, the total phenolics had the highest correlation to antioxidant activities (r=0.989 for DPPH assay and r=0.989 for FRAP assay). There was a significant positive correlation between the antioxidant activities measured by DPPH and FRAP assays (r=1.000), indicating that the antioxidant compounds in watermelon rind simultaneously exhibited antioxidant capacity by both mechanisms: DPPH radical scavenging and electron transfer (31).

The difference in color values for the three WR powder samples was so little and that was not detected by visual observation. The WR powder was slightly darker than the durum wheat semolina. Different coloring compounds such as carotenoids and anthocyanins are identified in durum wheat semolina (32) and WR (10), respectively. In addition, reducing sugars were presented in the WR powder. It can be inferred that Maillard reaction between reducing sugars and proteins could happen during the WR drying at 50 °C (33), resulting enhanced darkness for WR powder.

The WHC of WR powder was much greater than that of durum wheat semolina. Dietary fibers exhibit high affinity to water because of their hydroxyl groups (34). The smaller the mean particle size of WR powder sample, the lower the WHC due to its reduced total fiber content. In addition, the WR sample with reduced particle size was rich in pectin which could be partially lost in the aqueous phase during the determination of WHC (2). The reduction in WHC for pomelo peel powder sample with the decreased particle size was previously reported (35). Swelling of fiber materials is affected by their water absorption (34) and the WR powder

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sample with smaller particle size had lower SC. However, the WSI of WR powder gradually increased with the decrease in particle size because of the greater content of SDF (34).

Effect of particle size of watermelon rind powder on nutritional quality of pasta

Table 2 shows the nutritional quality of pasta samples. All WR added pasta samples contained much more dietary fiber than the control sample. The reduced particle size of WR powder enhanced SDF and pectin content of the pasta but decreased its TDF and IDF contents. According to the Codex Alimentarius (2013) Guidelines for Use of Nutrition and Health Claims (36), all WR-incorporated pasta samples in this study were classified as foods ‘high’ in fiber since their TDF contents were greater than 6 g/100 g dry mass. In addition, the IDF/SDF ratio of high fiber pasta samples was progressively decreased when the sieve aperture size of WR powder dropped from 400 to 149 µm. It can be concluded that all pasta samples supplemented with WR powder had a proper IDF/SDF ratio for human diet since the ratio was nearly within the range of [1-3] recommended by the American Dietetic Association (3,37). High IDF/SDF ratio is usually recorded in pasta fortified with cereal bran such as wheat bran (7.0) (3) or rice bran (9.0) (23). The use of WR powder in pasta formulation also enhanced the ash content but decreased its starch content. Nevertheless, the protein content of high-fiber pasta samples and that of the control sample were statistically similar. The change in nutritional quality of pasta samples was due to the difference in proximate composition of durum wheat semolina and WR powder.

Table 2

Effect of particle size of watermelon rind powder on in vitro bioaccessibility of phenolics, antioxidant activity and predicted glycemic index of pasta

The antioxidant contents and activities of all pasta samples are displayed Table 3 and Fig. 1, respectively. The addition of WR powder to pasta recipe greatly ameliorated total phenolic, flavonoid and anthocyanin levels of the uncooked product. When the sieve opening size decreased from 400 to 149 µm, the uncooked WR added pasta contained less anthocyanins while its TPC and TFC as well as antioxidant activities were significantly improved. That was due to the difference in phenolic levels of WR powder samples.

Table 3

The cooking operation reduced the TPC, TFC and TAC and antioxidant activities of all pasta samples. Phenolics are reported to be partially lost during pasta cooking due to oxidative degradation (38). The smaller the WR particle size, the greater the loss of phenolics and
antioxidant activities. It could be explained by the longer optimal cooking time of pasta fortified with WR powder with finer particles. In addition, the amount of phenolics and the DPPH scavenging activity of the cooked pasta supplemented with WR powder samples were 614 to 1023 mg GAE/kg dry mass and 3252 to 4642 μmol TE/kg dry mass, respectively, higher than those of the cooked control sample.

At the oral phase of the in vitro digestion, the TPC as well as the DPPH scavenging activity and ferric reducing powder liberated from all pasta samples were the lowest; flavonoids and anthocyanins were not detected. This is probably due to short exposure time to salivary amylase (2 min). The recent in vitro digestion shows that different flavonoids such as catechin, epicatechin in pasta supplemented with persimmon flour are not released at the oral digestion since they bind various organic compounds (21). The release of antioxidant contents and activities from the control and WR fortified pasta samples was greatly improved at the gastric phase; flavonoids and anthocyanins were observed in the gastric juice. It can be explained by acidic degradation of condensed tannin under low pH conditions (21) and proteolysis by pepsin (39,40), facilitating the release of bound phenolic molecules (21). At intestinal phase, both TPC and antioxidant activity of the control pasta remained nearly unchanged as compared to those at the gastric phase; nevertheless, the TPC, TFC and TAC and the DPPH radical scavenging activity and ferric reducing powder liberated from WR supplemented pasta samples all achieved maximal values. The main reason is probably due to the hydrolysis of starch, lipid, and protein at pH 7.0 by amylase, lipase, trypsin and other proteases in the simulated intestinal fluid (40); as a result, the release of bound phenolics from starch, lipid, and protein matrix could be improved. Similar increase in TPC and antioxidant activity is reported by Bustos et al. (39) when pasta prepared from berry fruits were used in the simulated digestion model. However, a lower TAC at the intestinal phase in comparison to that at the gastric phase was reported when the jaboticaba (Myrciaria trunciflora) fruit peel was used in the in vitro gastrointestinal digestion (41). Various results are due to difference in phenolic profile and interactions between phenolics and organic compounds in the plant materials. Detailed study on the release and stability of each phenolic compound from WR added pasta at different digestion phases is essential to clarify the impact of antioxidants of high-fiber pasta on human health. It can be noted that the larger the particle size of WR powder, the greater the antioxidant contents and activities liberated from the fortified pasta at the oral, gastric and intestinal phases of the in vitro digestion. It is reported that many phenolic compounds in watermelon rind bind to dietary fiber in the plant cell wall (42) and they might be released during the human digestion (37).
The bioaccessibility of total phenolics and predicted glycemic index of all pasta samples are presented in Fig 2.

Fig. 2

Fig. 2a reveals that the total phenolics bioaccessibility of WR fortified pasta was much greater than that of the control pasta. The pasta incorporated WR powder with the largest mean particle size had the highest phenolic bioaccessibility. The glycemic index (GI) (Fig. 2b) is an indicator to show how much a carbohydrate food increases the blood sugar level in human body. The control pasta sample had the highest pGI since it had the highest starch content. Although the three WR incorporated pasta samples had similar starch content, the increased pGI was recorded for the sample supplemented with WR powder with reduced mean particle size. It can be explained by the reduced TDF content. Insoluble fiber-rich fractions decreased the swelling of starch granules in cooked pasta due to their high-water absorption, resulting in the limited starch hydrolysis (3,43). Furthermore, the interaction of dietary fiber with starch (43), as well as the complex formation of soluble fibers (3) and polyphenols (43) with α-amylase, could limit the accessibility of amylase to starch granules in pasta. The P400 sample was considered a low pGI product (pGI<55), while the other WR-added pasta samples were in the medium pGI category (55<pGI<70); the control pasta sample was considered a high pGI product (44). The diet with low pGI products might reduce the risk of acquiring obesity, diabetes, and cardiovascular disease (3). It can be confirmed that the supplementation of WR powder to the pasta recipe significantly reduced the predicted glycemic index of the product.

Effect of particle size of watermelon rind powder on texture quality and instrumental color of pasta

Table 4 demonstrates textural attributes of the cooked pasta samples and color values of the uncooked ones.

Table 4

The use of WR powder in pasta formulation enhanced the product hardness. Possibly, high degree of polymerization and crystallization of IDF of WR powder (45) could increase the hardness of WR-added pasta (46). When the sieve aperture size was reduced from 400 to 149 μm, the hardness of pasta samples gradually decreased probably due to the reduced IDF content. Adhesiveness shows the force required to overcome the attractive forces between the food surface and the probe surface to which the food comes in contact. The control pasta sample had the lowest adhesiveness. The adhesiveness of fiber-rich pasta roughly increased when the particle size of WR powder was increased. It can be attributed to fiber components
that disrupt the protein-starch network, resulting in a greater release of exudates from pasta strands into cooking water, leading to the increased adhesiveness (47). During our experimentation, it was observed that the higher the pasta fiber content, the greater the number of water droplets on pasta strand surface after the same draining time. The use of WR powder in pasta formulation significantly decreased elongation rate and tensile strength of the pasta since the reduced gluten content and the presence of dietary fiber in gluten network of pasta dough could reduce its continuity (3,48). Moreover, fibers could change β-sheets structure of gluten, leading to protein folding as well as preventing the formation of disulfide bonds for gluten linkage (49,50), resulting in the reduced tensile strength. The improved elongation rate and tensile strength of high fiber pasta were accompanied by a decrease in WR particle size.

The lightness of WR supplemented pasta samples was slightly less than that of the control pasta (Fig. 3b) since the WR powder was darker than the durum wheat semolina (Fig. 3a). The change in WR particle means size had a little effect on the color of high-fiber pasta samples and these changes were not perceptible by eye.

Effect of particle size of watermelon rind powder on cooking quality and sensory overall acceptability of pasta

Table 5 reveals that the OCT of high fiber pasta samples was shorter while their CL was significantly higher than those of the control pasta probably owing to a decreased gluten content (3,47). Low OCT could save more cooking energy and limit the loss of bioactive compounds. It can be noted that the CL of all pasta samples incorporated with WR was lower than the acceptable limit (8%) (9). When the aperture sieve size for WR powder decreased from 400 to 149 µm, the OCT of high-fiber pasta was steadily prolonged while its CL was dropped by 15%; it is probably due to a better distribution of WR particles in pasta dough since the obtained WR powder sample had a reduced span value (Table 1), resulting in the improved gluten network. Similar decrease in CL was also recorded when the potato peel powder with fine particles was added to pasta formulation (27). In addition, WR powder with large particle size could disrupt more gluten network, making pasta with a less uniform texture, accelerating starch gelatinization through increased diffusion of cooking water (48).

Table 5

Change in particle size of WR powder did not alter the SI of high-fiber pasta samples but their SI was lower than that of the control possibly because of the reduction in starch content (46).
Similarly, the WAI of the control pasta was slightly greater than that of the high fiber pasta. The use of WR powder with reduced particle size enhanced the WAI of high fiber pasta because of enhanced OCT, improving water absorption of starch, fiber and protein during the cooking process (46). The sensory overall acceptability was statistically equivalent for all pasta samples. The change in particle size of WR powder did not affect the acceptance level of the pasta.

CONCLUSIONS

The particle size of WR powder, whether large or small, had various impacts on the high-fiber pasta quality. The use of WR powder with increased particle size generated in pasta with elevated dietary fiber content, improved antioxidant activity and bioaccessibility, and decreased glycemic index; meanwhile the texture, color and cooking quality of the functionalized pasta was reduced. However, there was no discernible difference in overall acceptability between the control pasta sample and the three high-fiber pasta samples supplemented with WR powder passed through sieves of 400, 210, and 149-μm apertures. In the future, the bioaccessibility of each phenolic compound in the WR-supplemented pasta should be investigated at each digestion step for a better understanding of phenolic metabolism in human nutrition. Furthermore, the impacts of particle size of dietary fiber material in functional pasta products on the gut microbiota and colonic proliferation should be investigated.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS’ CONTRIBUTION

D.Q. Long designed and performed the experiments, analysed data and wrote the manuscript. T.M. Trieu contributed to conducting the experiments, data collection and
discussion. T.T.T. Tran, N.M.N. Ton contributed to the data interpretation and revision. V.V.M. Le was in charge of the supervision and final revision of the manuscript.

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Fig. 1. Antioxidant activity of pasta sample according to a) DPPH, and b) FRAP assays. Values with different lowercase letters (a–d) in the same legend and uppercase (A–E) in the same sample are significantly different (p<0.05). DM=dry mass, TE=Trolox equivalent, FRAP=ferric reducing antioxidant power, DPPH=2,2-diphenyl-1-picrylhydrazyl radical scavenging activity, P400, P210, and P149=pasta incorporated with 10% watermelon rind powder passed through 400, 210, and 149-μm aperture sieve, respectively.
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**Fig. 2.** a) Bioaccessibility of total phenolics, and b) predicted glycemic index of pasta samples. Values with different lowercase letters (a–d) in the same chart are significantly different (p<0.05). P400, P210, and P149=pasta incorporated with 10 % watermelon rind powder passed through 400, 210, and 149-μm aperture sieve, respectively
Fig. 3. Picture of: a) WR powder and durum wheat semolina, and b) uncooked pasta fortified with WR and control pasta. WR=watermelon rind, P400, P210, and P149=pasta incorporated with 10% watermelon rind powder passed through 400, 210, and 149-μm aperture sieve, respectively.
Table 1. Nutritional quality, antioxidant activity, and physical properties of watermelon rind powder and durum wheat semolina

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Watermelon rind powder passed through sieve</th>
<th>Durum wheat semolina</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size particle range/μm</td>
<td>4 – 1849</td>
<td>2 – 3080</td>
</tr>
<tr>
<td>D₄₃.₃/μm</td>
<td>(148±7)c</td>
<td>(183±6)d</td>
</tr>
<tr>
<td>Aₙ₀/(m²/kg)</td>
<td>(271.5±5.1)a</td>
<td>(277.4±14.3)a</td>
</tr>
<tr>
<td>SPAN</td>
<td>(3.2±0.1)d</td>
<td>(2.9±0.1)c</td>
</tr>
<tr>
<td>ρ/(g/cm³)</td>
<td>(0.351±0.004)a</td>
<td>(0.831±0.010)d</td>
</tr>
<tr>
<td>w(water)/%</td>
<td>(7.8±0.4)a</td>
<td>(12.4±0.1)b</td>
</tr>
<tr>
<td>w(TDF)/(g/100g DM)</td>
<td>(41.7±0.4)d</td>
<td>(3.6±0.0)a</td>
</tr>
<tr>
<td>w(IDF)/(g/100g DM)</td>
<td>(29.6±0.8)d</td>
<td>(2.7±0.1)a</td>
</tr>
<tr>
<td>w(SDF)/(g/100g DM)</td>
<td>(12.2±0.3)b</td>
<td>(0.8±0.0)a</td>
</tr>
<tr>
<td>w(pectin)/(g/100g DM)</td>
<td>(7.5±0.5)a</td>
<td>n.d.</td>
</tr>
<tr>
<td>ζ(IDF/SDF)/(g/g)</td>
<td>(2.4±0.1)c</td>
<td>(3.4±0.2)d</td>
</tr>
<tr>
<td>w(starch)/(g/100g DM)</td>
<td>(2.5±0.1)a</td>
<td>(70.7±1.4)b</td>
</tr>
<tr>
<td>w(total sugar)/(g/100g DM)</td>
<td>(9.5±0.3)b</td>
<td>(3.7±0.0)a</td>
</tr>
<tr>
<td>w(reducing sugar)/(g/100g DM)</td>
<td>(7.5±0.2)b</td>
<td>(0.7±0.0)a</td>
</tr>
<tr>
<td>w(protein)/(g/100g DM)</td>
<td>(13.0±0.3)a</td>
<td>(13.3±0.4)ab</td>
</tr>
<tr>
<td>w(lipid)/(g/100g DM)</td>
<td>(2.9±0.1)d</td>
<td>(1.8±0.1)a</td>
</tr>
<tr>
<td>w(ash)/(g/100g DM)</td>
<td>(12.8±0.1)d</td>
<td>(0.5±0.2)a</td>
</tr>
<tr>
<td>Total phenolics as w(GAE)/(mg/kg DM)</td>
<td>(7128±152)b</td>
<td>(269±7)a</td>
</tr>
<tr>
<td>Total flavonoids as w(QE)/(mg/kg DM)</td>
<td>(4433±11)a</td>
<td>n.d.</td>
</tr>
<tr>
<td>Total anthocyanin as w(CGE)/(mg/kg DM)</td>
<td>(393±19)c</td>
<td>n.d.</td>
</tr>
<tr>
<td>DPPH radical scavenging activity as b(TE)/(μmol/kg DM)</td>
<td>(27186±1295)b</td>
<td>(2499±58)a</td>
</tr>
</tbody>
</table>
Ferric reducing power as $\text{b}(\text{TE})/\mu\text{mol/kg DM}$

<table>
<thead>
<tr>
<th></th>
<th>(11862±467)$^b$</th>
<th>(18223±807)$^c$</th>
<th>(21141±947)$^d$</th>
<th>(1148±14)$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L^*$</td>
<td>(81.0±0.1)$^a$</td>
<td>(81.1±0.0)$^a$</td>
<td>(81.6±0.3)$^b$</td>
<td>(91.2±0.0)$^c$</td>
</tr>
<tr>
<td>$a^*$</td>
<td>(2.3±0.0)$^b$</td>
<td>(2.7±0.0)$^c$</td>
<td>(2.7±0.0)$^c$</td>
<td>(0.9±0.0)$^a$</td>
</tr>
<tr>
<td>$b^*$</td>
<td>(19.6±0.1)$^b$</td>
<td>(20.3±0.0)$^c$</td>
<td>(20.8±0.1)$^d$</td>
<td>(10.0±0.0)$^a$</td>
</tr>
<tr>
<td>WHC/(g/g)</td>
<td>(5.9±0.1)$^d$</td>
<td>(5.1±0.0)$^c$</td>
<td>(4.7±0.1)$^b$</td>
<td>(0.9±0.0)$^a$</td>
</tr>
<tr>
<td>SC/(mL/g)</td>
<td>(10.4±0.2)$^d$</td>
<td>(7.0±0.3)$^c$</td>
<td>(5.9±0.1)$^b$</td>
<td>(1.0±0.0)$^a$</td>
</tr>
<tr>
<td>WSI/%</td>
<td>(42.2±0.2)$^b$</td>
<td>(44.9±0.3)$^c$</td>
<td>(47.3±0.8)$^d$</td>
<td>(13.1±0.5)$^a$</td>
</tr>
</tbody>
</table>

Values with different lowercase letters (a–d) in the same row are significantly different (p<0.05). n.d.=not detected, DM=dry mass, TDF=total dietary fiber, IDF=insoluble dietary fiber, SDF=soluble dietary fiber, GAE=gallic acid equivalent, QE=quercetin equivalent, CGE=cyanidin-3-glucoside equivalent, DPPH=2,2-diphenyl-1-picrylhydrazyl, TE=Trolox equivalent, WHC=water holding capacity, SC=swelling capacity, WSI=water solubility index.
Table 2. Nutritional quality of uncooked pasta samples

<table>
<thead>
<tr>
<th>Parameter</th>
<th>P400</th>
<th>P210</th>
<th>P149</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>w(water)/%</td>
<td>(10.0±0.1)ᵃ</td>
<td>(10.0±0.1)ᵃ</td>
<td>(10.1±0.1)ᵃ</td>
<td>(12.3±0.1)ᵇ</td>
</tr>
<tr>
<td>w(TDF)/(g/100g DM)</td>
<td>(7.5±0.1)ᵈ</td>
<td>(7.3±0.1)ᶜ</td>
<td>(6.9±0.2)ᵇ</td>
<td>(3.6±0.1)ᵃ</td>
</tr>
<tr>
<td>w(IDF)/(g/100g DM)</td>
<td>(5.7±0.1)ᵈ</td>
<td>(5.3±0.1)ᶜ</td>
<td>(4.8±0.2)ᵇ</td>
<td>(2.9±0.1)ᵃ</td>
</tr>
<tr>
<td>w(SDF)/(g/100g DM)</td>
<td>(1.8±0.1)ᵇ</td>
<td>(2.0±0.1)ᶜ</td>
<td>(2.1±0.1)ᵈ</td>
<td>(0.7±0.0)ᵃ</td>
</tr>
<tr>
<td>w(pectin)/(g/100g DM)</td>
<td>(1.0±0.1)ᵃ</td>
<td>(1.2±0.1)ᵇ</td>
<td>(1.4±0.1)ᶜ</td>
<td>n.d.</td>
</tr>
<tr>
<td>ζ(IDF/SDF)/(g/g)</td>
<td>(3.2±0.2)ᶜ</td>
<td>(2.6±0.1)ᵇ</td>
<td>(2.3±0.2)ᵃ</td>
<td>(4.0±0.2)ᵈ</td>
</tr>
<tr>
<td>w(starch)/(g/100g DM)</td>
<td>(63.5±2.1)ᵃ</td>
<td>(63.4±0.8)ᵃ</td>
<td>(64.4±1.1)ᵃ</td>
<td>(71.2±1.7)ᵇ</td>
</tr>
<tr>
<td>w(protein)/(g/100g DM)</td>
<td>(13.3±0.5)ᵃ</td>
<td>(13.4±0.4)ᵃ</td>
<td>(13.5±0.3)ᵃ</td>
<td>(13.0±0.5)ᵃ</td>
</tr>
<tr>
<td>w(lipid)/(g/100g DM)</td>
<td>(2.1±0.1)ᵇ</td>
<td>(2.1±0.1)ᵇ</td>
<td>(2.0±0.1)ᵇ</td>
<td>(1.8±0.1)ᵃ</td>
</tr>
<tr>
<td>w(ash)/(g/100g DM)</td>
<td>(1.6±0.1)ᵇ</td>
<td>(1.6±0.0)ᵇ</td>
<td>(1.6±0.1)ᵇ</td>
<td>(0.8±0.0)ᵃ</td>
</tr>
</tbody>
</table>

Values with different lowercase letters (a–d) in the same row are significantly different (p<0.05). n.d. = not detected, DM = dry mass, TDF = total dietary fiber, IDF = insoluble dietary fiber, SDF = soluble dietary fiber, P400, P210, and P149 = pasta incorporated with 10% watermelon rind powder passed through 400, 210, and 149-μm aperture sieve, respectively.
Table 3. Bioactive compounds of pasta samples

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Uncooked pasta</th>
<th>Cooked pasta</th>
<th>Cooked pasta during the <em>in vitro</em> digestion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Oral</td>
</tr>
<tr>
<td>Total phenolics as w(GAE)/(mg/kg DM)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P400</td>
<td>(1291±35)&lt;sup&gt;b,C&lt;/sup&gt;</td>
<td>(1023±50)&lt;sup&gt;d,B&lt;/sup&gt;</td>
<td>(200±8)&lt;sup&gt;d,A&lt;/sup&gt;</td>
</tr>
<tr>
<td>P210</td>
<td>(1457±72)&lt;sup&gt;c,D&lt;/sup&gt;</td>
<td>(769±35)&lt;sup&gt;c,B&lt;/sup&gt;</td>
<td>(137±4)&lt;sup&gt;c,A&lt;/sup&gt;</td>
</tr>
<tr>
<td>P149</td>
<td>(1668±72)&lt;sup&gt;d,E&lt;/sup&gt;</td>
<td>(614±28)&lt;sup&gt;b,B&lt;/sup&gt;</td>
<td>(84±0)&lt;sup&gt;b,A&lt;/sup&gt;</td>
</tr>
<tr>
<td>Control</td>
<td>(353±13)&lt;sup&gt;a,D&lt;/sup&gt;</td>
<td>(292±6)&lt;sup&gt;a,C&lt;/sup&gt;</td>
<td>(49±0)&lt;sup&gt;a,A&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total flavonoids as w(QE)/(mg/kg DM)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P400</td>
<td>(800±28)&lt;sup&gt;a,B&lt;/sup&gt;</td>
<td>(655±15)&lt;sup&gt;c,A&lt;/sup&gt;</td>
<td>n.d.</td>
</tr>
<tr>
<td>P210</td>
<td>(857±26)&lt;sup&gt;b,D&lt;/sup&gt;</td>
<td>(462±22)&lt;sup&gt;b,A&lt;/sup&gt;</td>
<td>n.d.</td>
</tr>
<tr>
<td>P149</td>
<td>(978±39)&lt;sup&gt;c,D&lt;/sup&gt;</td>
<td>(371±12)&lt;sup&gt;a,A&lt;/sup&gt;</td>
<td>n.d.</td>
</tr>
<tr>
<td>Total anthocyanin as w(CGE)/(mg/kg DM)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P400</td>
<td>(74±2)&lt;sup&gt;c,B&lt;/sup&gt;</td>
<td>(56±2)&lt;sup&gt;c,A&lt;/sup&gt;</td>
<td>n.d.</td>
</tr>
<tr>
<td>P210</td>
<td>(70±2)&lt;sup&gt;b,C&lt;/sup&gt;</td>
<td>(36±1)&lt;sup&gt;b,A&lt;/sup&gt;</td>
<td>n.d.</td>
</tr>
<tr>
<td>P149</td>
<td>(65±3)&lt;sup&gt;a,D&lt;/sup&gt;</td>
<td>(22±1)&lt;sup&gt;a,A&lt;/sup&gt;</td>
<td>n.d.</td>
</tr>
<tr>
<td>Correlation value (r)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPC and antioxidant activity based on DPPH assay</td>
<td>0.998</td>
<td>0.929</td>
<td>0.978</td>
</tr>
<tr>
<td>TPC and antioxidant activity based on FRAP assay</td>
<td>0.998</td>
<td>0.942</td>
<td>0.932</td>
</tr>
<tr>
<td>DPPH scavenging activity and ferric reducing power</td>
<td>0.992</td>
<td>0.999</td>
<td>0.987</td>
</tr>
</tbody>
</table>
Values with different uppercase letters (A–E) in the same row and lowercase letters (a–d) in the same column are significantly different (p<0.05). n.d.=not detected, DM=dry mass, GAE=galllic acid equivalent, QE=quercetin equivalent, CGE=cyanidin-3-glucoside equivalent, TPC=total phenolic content, FRAP=ferric reducing antioxidant power, DPPH=2,2-diphenyl-1-picrylhydrazyl radical scavenging activity, P400, P210, and P149=pasta incorporated with 10% watermelon rind powder passed through 400, 210, and 149-μm aperture sieve, respectively.
Table 4. Textural attributes of cooked pasta and instrumental color values of uncooked pasta samples

<table>
<thead>
<tr>
<th>Parameter</th>
<th>P400</th>
<th>P210</th>
<th>P149</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness/g</td>
<td>(2664±106)^d</td>
<td>(2463±109)^c</td>
<td>(2328±105)^b</td>
<td>(2008±56)^a</td>
</tr>
<tr>
<td>Adhesiveness</td>
<td>(14.68±0.36)^d</td>
<td>(13.03±0.30)^c</td>
<td>(12.23±0.34)^b</td>
<td>(10.64±0.50)^a</td>
</tr>
<tr>
<td>Tensile strength/kPa</td>
<td>(22.2±0.7)^a</td>
<td>(23.5±0.6)^b</td>
<td>(25.0±0.8)^c</td>
<td>(27.1±0.6)^d</td>
</tr>
<tr>
<td>Elongation rate/%</td>
<td>(32.3±1.2)^a</td>
<td>(41.1±1.2)^b</td>
<td>(45.2±3.1)^c</td>
<td>(57.3±1.1)^d</td>
</tr>
<tr>
<td>L*</td>
<td>(87.4±0.1)^a</td>
<td>(87.6±0.2)^b</td>
<td>(87.8±0.0)^c</td>
<td>(89.3±0.0)^d</td>
</tr>
<tr>
<td>a*</td>
<td>(1.2±0.0)^b</td>
<td>(1.4±0.1)^c</td>
<td>(1.4±0.0)^c</td>
<td>(1.1±0.0)^a</td>
</tr>
<tr>
<td>b*</td>
<td>(11.8±0.1)^b</td>
<td>(12.4±0.0)^c</td>
<td>(12.8±0.1)^d</td>
<td>(8.7±0.0)^a</td>
</tr>
<tr>
<td>ΔE</td>
<td>(3.6±0.1)^b</td>
<td>(4.0±0.1)^c</td>
<td>(4.3±0.0)^d</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

Values with different lowercase letters (a–d) in the same chart are significantly different (p<0.05). n.a.=not application, P400, P210, and P149=pasta incorporated with 10% watermelon rind powder passed through 400, 210, and 149-μm aperture sieve, respectively.
Table 5. Cooking quality and overall acceptability of cooked pasta samples

<table>
<thead>
<tr>
<th>Parameter</th>
<th>P400</th>
<th>P210</th>
<th>P149</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal cooking time/min</td>
<td>(10.8±0.3)(^a)</td>
<td>(11.9±0.2)(^b)</td>
<td>(12.7±0.3)(^c)</td>
<td>(13.9±0.2)(^d)</td>
</tr>
<tr>
<td>Cooking loss/%</td>
<td>(6.6±0.3)(^d)</td>
<td>(6.1±0.2)(^c)</td>
<td>(5.6±0.2)(^b)</td>
<td>(4.6±0.1)(^a)</td>
</tr>
<tr>
<td>Swelling index</td>
<td>(1.67±0.02)(^a)</td>
<td>(1.69±0.00)(^a)</td>
<td>(1.69±0.08)(^a)</td>
<td>(1.83±0.05)(^b)</td>
</tr>
<tr>
<td>Water absorption index</td>
<td>(1.22±0.02)(^a)</td>
<td>(1.29±0.04)(^b)</td>
<td>(1.40±0.03)(^c)</td>
<td>(1.56±0.04)(^d)</td>
</tr>
<tr>
<td>Overall acceptability</td>
<td>(6.3±1.0)(^a)</td>
<td>(6.2±1.0)(^a)</td>
<td>(5.9±1.1)(^a)</td>
<td>(6.3±1.1)(^a)</td>
</tr>
</tbody>
</table>

Values with different lowercase letters (a–d) in the same row are significantly different (p<0.05). P400, P210, and P149=pasta incorporated with 10% watermelon rind powder passed through 400, 210, and 149-μm aperture sieve, respectively.