Total phenolic, flavonoid content, and antioxidant activity of flour, noodles, and steamed bread made from different colored wheat grains by three milling methods

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ABSTRACT

The objective of this study was to evaluate the effects of wheat variety, food processing, and milling method on antioxidant properties. Black wheat variety Heibaoshi 1 had the highest total phenolic content (659.8 μg gallic acid equivalents g⁻¹), total flavonoid content (319.3 μg rutin equivalents g⁻¹), and antioxidant activity, whereas light purple wheat variety Shandongzimai 1 had the lowest total flavonoid content (236.2 μg rutin equivalents g⁻¹) and antioxidant activity. Whole wheat flour and partially debranned grain flour had significantly higher total phenolic contents, total flavonoid contents, and antioxidant activity than refined flour (P < 0.05). Compared with flour, total phenolic contents, total flavonoid contents and antioxidant activity decreased in noodles and steamed bread, whereas noodles had slightly higher total phenolic and flavonoid content than steamed bread. Antioxidant activities (by ferric reducing ability of plasma assay) of steamed bread made from whole wheat flour, partially debranned grain flour, and refined flour were 23.5%, 21.1%, and 31.6% lower, respectively, than the corresponding values of flour. These results suggested that black whole wheat flour and partially debranned grain flour are beneficial to human health.

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Milling method
Antioxidant activity
Colored wheat

1. Introduction

Free radicals contribute to cancer, atherosclerosis, malaria, and rheumatoid arthritis and neurodegenerative diseases [1]. In the scientific and medical communities, antioxidants are considered to have the ability to scavenge free radicals and reduce oxidative damage [2,3]. Accordingly, increased consumption of fruits and vegetables containing high levels of antioxidants has been recommended. However, wheat, one of the most important grains in the world, is not only a source of basic nutrients, such as carbohydrates, proteins, and vitamins, but also a source of antioxidants, such as flavonoids.
and phenolic acids [4]. Wu et al. [5] reported that the antioxidant activity of whole grain including whole wheat bread ranged from 1303 to 2479 μmol trolox equivalent (TE) per 100 g, whereas the average values of 24 types of fruit and 22 types of vegetables were 2200 and 1200 μmol TE per 100 g, respectively. These results indicated that whole grains have pronounced antioxidant activities that should not be overlooked. Regular consumption of these bioactive compounds could reduce the risk of cardiovascular diseases and cancer [6].

These bioactive compounds are mainly located in the outer membranes of the grain [7]. The bran fraction contains markedly higher concentrations of phenolic acids than those in white flour [8]. Conventional modern milling methods, which remove most of the bran and germ, reduce the amounts of total phenolics and flavonoids in wheat products [4]. Wang et al. [9] found that the grain phenolic acid concentrations ranged from 54 μg g⁻¹ in flour produced at 60% extraction rate to 695 μg g⁻¹ in flour produced at 100% extraction rate. Given that the regular consumption of whole wheat products reduces the risk of heart disease and cancer [4,6], gradual or whole-wheat milling has been developed to retain nutrients and bioactive compounds [10,11]. However, food processing also affects the antioxidant properties of foods to different extents. Wu et al. [5] found that processing methods (including cooking and hulling) affected oxygen radical absorbance capacity. Chlopicka et al. [12] reported that total flavonoid content (TFC) of flour was approximately 2–4-fold higher than that in breads. Noodles and steamed bread are the most widely consumed wheat products in China. Researchers have focused on flour noodle and steamed bread sensory qualities [13,14], and there is little information on the antioxidant properties of these products.

Recently, much attention has been focused on colored wheat varieties. Black-grained wheat has been reported to have high free radical scavenging ability and phenolic content [15]. Purple and black wheat varieties have high protein content and antioxidant activity (AOA), owing to the presence of phenolic acid and vitamin C [16,17]. Similarly, green wheat bran has high AOA, which is positively correlated with pigmentation [18]. The relationships between grain color and nutrient qualities have been reported by Zong et al. [19]. Colored wheat, which has high levels of anthocyanins, suppresses oxidation and nitric oxide formation in vitro [20]. However, there has been some disagreement about the relationship between total phenolic content and antioxidant activity and grain color. Mpofu et al. [21] found that grain color does not appear to be a factor in the expression of antioxidant-related parameters. Colored wheat with lower antioxidant activity was also reported by Liu et al. [17]. In our previous report, some white wheat varieties showed a higher total phenolic content (TPC) and antioxidant activities than black wheat varieties [22]. Similar results have been found in rice [23]. To clarify the effect of grain color, milling methods and food types on antioxidant content and its activities, three colored wheat varieties (deep purple, light purple, and black) and one white wheat variety were milled to different degrees (yielding whole wheat flour, partially debranned grain flour, and refined flour). TPC, TFC, and AOA of the different flours, Chinese fresh noodles, and steamed bread were analyzed.

## 2. Materials and methods

### 2.1. Materials

Four different colored wheat (Triticum aestivum L.) varieties were collected from the 2013 harvest at Henan Agricultural University Experimental Station: white Yumai 49-198 (YU), deep purple Jizi 439 (JZ), light purple Shandongzimai 1 (SDZM), and black wheat Heibaoshi 1 (HBS). Seeds were cleaned and stored at room temperature and damaged seeds were removed. Three milling methods were used, yielding whole wheat flour (WWF), partially debranned grain flour (PGF), and refined wheat flour (RF). To prepare WWF, whole wheat kernels were milled in a Cyclotec 1093 mill (Foss Tecator, Höganäs, Sweden) without removal of bran or germ. To prepare PGF, whole wheat kernels were first stripped of the bran layer using a grain polisher (TYT200, Tianyang Machinery Co. Ltd., Shandong, China) and then milled. Hulling degree was calculated as the difference between the initial sample weight and the hulled grain weight, relative to the initial sample weight, and was approximately 5.0%. To prepare RF, wheat kernels were milled into refined flour in a Brabender Junior laboratory mill (method 26-21A, AACC, 1995). All sample flours were passed through 80-mesh sieves (sieve size: 0.180 mm).

### 2.2. Noodle and steamed bread making

Chinese fresh noodles were prepared as described by Zhang et al. [24]. Fresh noodles (50 g) were cooked in 1000 mL distilled water, rinsed with cold water, and allowed to cool to room temperature. The noodles were then dried and milled into noodle powder with a small grinder (FW100, Taisite Co. Ltd., Tianjin, China).

Chinese steamed breads were prepared as described by Chen et al. [25]. After cooking, steamed breads were allowed to cool at room temperature, sliced 1.5 cm thick, and oven-dried at 40 °C. The steamed bread slices were milled into bread powder with the FW100 grinder. For each sample, two replicates were prepared for noodles and steamed breads.

### 2.3. Extract preparation

Total phenolics were extracted from the samples by the method of Moore [26], with slight modifications. Briefly, flour samples (2.0 g) were mixed with 16 mL of methanol containing 1% HCl for 24 h at 24 °C. The procedure was repeated twice. The methanol extracts were centrifuged at 4000 × 9.81 (m s⁻²) for 15 min and the resulting supernatants were pooled and stored at 4 °C.

### 2.4. TPC

TPC was determined by the method of Singleton [27], with slight modifications. Extracts (0.5 mL) were mixed with 5 mL of Folin–Ciocalteu reagent (1 mol), neutralized with 4 mL saturated sodium carbonate (75 g L⁻¹), and kept at room temperature for 2 h. Absorbance at 765 nm was measured with a spectrophotometer. TPC was expressed as gallic acid equivalents (mg GAE g⁻¹ dry weight).
2.5. TFC

TFC was determined by a colorimetric method with minor modifications [23]. Aliquots (0.5 mL) of diluted extracts or standard solutions were transferred into 15-mL polypropylene conical tubes containing 2 mL double distilled H₂O and 0.15 mL of 5% NaNO₂. After 5 min, 0.15 mL of 10% AlCl₃·6H₂O solution was added, and the mixture was allowed to stand for another 5 min, after which 1 mL of 1 mol L⁻¹ NaOH was added. The solution was mixed and allowed to stand for 15 min. Absorbance was measured at 415 nm. TFC was calculated from a standard rutin curve and expressed as rutin equivalents (μgRE g⁻¹ dry weight).

2.6. AOA by FRAP assay

The FRAP (Ferric Reducing Ability of Plasma) assay was performed by the method of Benzie & Strain [28], with slight modifications. Briefly, 0.5 mL of diluted extracts or standard solutions were mixed with 1.8 mL TPTZ solution (25 mL of 0.3 mol L⁻¹ acetate buffer, 2.5 mL of 10 mmol L⁻¹ TPTZ (2,4,6-tripyridyl-s-triazine), and 2.5 mL of 20 mmol L⁻¹ FeCl₃). The mixture was conditioned at 37 °C for 10 min. Absorbance was measured at 593 nm. FRAP values were expressed as FeSO₄ equivalents (mmol L⁻¹ FeSO₄ g⁻¹ dry weight).

2.7. AOA by ABTS⁺ assay

The ABTS⁺ [2,2-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid)] assay was performed [23]. ABTS⁺ (3.9 mL) was added to the extracts (0.1 mL) and thoroughly mixed. The mixture was held at room temperature for 6 min, and absorbance was immediately measured at 734 nm. Trolox standard solution in 80% ethanol was prepared and assayed under the same conditions. The results were expressed in terms of Trolox equivalents (μmol TE g⁻¹ dry weight).

2.8. Statistical analyses

Data were analyzed by analysis of variance (ANOVA) and Duncan’s multiple-range tests using SPSS (Statistical Product and Service Solutions) software (IBM SPSS, USA). Statistical significance was set at \( P < 0.05 \).

3. Results

3.1. ANOVA results

Wheat variety, milling method, and food type affected TPC, TFC, ABTS⁺, and FRAP (\( P < 0.01 \); Table 1). Interactions between wheat variety and milling method, wheat variety and food type, and milling method and food type were significant. The effect of food type was considerably higher than those of wheat variety and milling method for TPC, TFC, and ABTS⁺. Interestingly, for FRAP, the milling effect was significantly greater than that of wheat variety and food type. Thus, milling method and food type were the main factors affecting antioxidant properties.

### Table 1 – Mean square values from analysis of variance for total phenolic content, total flavonoid content, and antioxidant activities of flour from different wheat varieties by three milling methods and food types.

<table>
<thead>
<tr>
<th>Sources of variation</th>
<th>df</th>
<th>TPC (μg GAE g⁻¹)</th>
<th>TFC (μg RE g⁻¹)</th>
<th>ABTS⁺ (mmol L⁻¹ FeSO₄ g⁻¹)</th>
<th>FRAP (μmol L⁻¹ TE g⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety (V)</td>
<td>3</td>
<td>85,409.1**</td>
<td>23,124.1**</td>
<td>1.00**</td>
<td>246.7**</td>
</tr>
<tr>
<td>Milling method (M)</td>
<td>2</td>
<td>1,177,545.6**</td>
<td>483,701.2**</td>
<td>5.70**</td>
<td>6019.0**</td>
</tr>
<tr>
<td>Food type (F)</td>
<td>2</td>
<td>5,666,346.6**</td>
<td>1,655,312.8**</td>
<td>21.00**</td>
<td>373.9**</td>
</tr>
<tr>
<td>V × M</td>
<td>6</td>
<td>17,843.8**</td>
<td>2553.6*</td>
<td>0.20**</td>
<td>89.8**</td>
</tr>
<tr>
<td>V × F</td>
<td>6</td>
<td>36,683.1**</td>
<td>2721.4**</td>
<td>0.10**</td>
<td>29.5**</td>
</tr>
<tr>
<td>F × M</td>
<td>4</td>
<td>386,016.1**</td>
<td>248,794.9**</td>
<td>0.30**</td>
<td>29.3**</td>
</tr>
<tr>
<td>V × M × F</td>
<td>12</td>
<td>8741.7**</td>
<td>2098.9*</td>
<td>0.10**</td>
<td>18.6**</td>
</tr>
<tr>
<td>Error</td>
<td>36</td>
<td>499.2</td>
<td>813.8</td>
<td>0.04</td>
<td>8.6*</td>
</tr>
</tbody>
</table>

TPC, TFC: total phenolic content and total flavonoid content, respectively.
V, M, F: variety, milling method, and food type, respectively.
* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.

### Table 2 – Antioxidant properties of different wheat varieties.

<table>
<thead>
<tr>
<th>Variety</th>
<th>TPC (μg GAE g⁻¹)</th>
<th>TFC (μg RE g⁻¹)</th>
<th>ABTS⁺ (mmol L⁻¹ FeSO₄ g⁻¹)</th>
<th>FRAP (μmol L⁻¹ TE g⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>YU</td>
<td>506.5 d</td>
<td>253.2 bc</td>
<td>10.0 a</td>
<td>31.7 b</td>
</tr>
<tr>
<td>SDZM</td>
<td>525.9 c</td>
<td>236.2 c</td>
<td>9.5 c</td>
<td>28.1 c</td>
</tr>
<tr>
<td>JZ</td>
<td>544.1 b</td>
<td>271.4 b</td>
<td>9.8 b</td>
<td>28.2 c</td>
</tr>
<tr>
<td>HBS</td>
<td>659.8 a</td>
<td>319.3 a</td>
<td>9.9 ab</td>
<td>35.9 a</td>
</tr>
</tbody>
</table>

Means in the same column followed by different letters are significantly different (\( P < 0.05 \)).
TPC, TFC: total phenolic content and total flavonoid content, respectively.
3.2. Antioxidant properties of different varieties

As shown in Table 2, antioxidant properties differed significantly among the wheat varieties. The highest and lowest TPC values were observed in black wheat HBS (659.8 μg GAE g⁻¹) and white wheat YU (506.5 μg GAE g⁻¹), respectively. HBS had the highest and SDZM the lowest TFC and FRAP values. Interestingly, the highest ABTS⁺ value was observed in YU, with no significant difference between YU and HBS. The results revealed that colored wheat did not consistently have higher antioxidant properties than white wheat.

3.3. Antioxidant properties of milling methods

There were significant differences in TPC, TFC, ABTS⁺, and FRAP among the different milling methods (Table 3). WWF and RF had the highest and lowest antioxidant values, respectively. Compared with TPC of WWF, TPC of PGF and RF was decreased by 16.9% and 57.8%, respectively. RF milling method significantly decreased AOA based on ABTS⁺ and FRAP results. The most significant reduction was obtained by the FRAP assay. Compared with FRAP of WWF, FRAP of PGF and RF decreased by 20.9% and 69.6%, respectively.

3.4. Antioxidant properties of food types

Food processing significantly decreased antioxidant properties (Table 4). Flour had the highest TPC, followed by noodles and steamed bread. Compared with TPC of flour, TPC of noodles and steamed bread was decreased by 70.1% and 79.7%, respectively. Similar trends were observed with TFC and FRAP. However, noodles had lower ABTS⁺ values than steamed bread.

3.5. Antioxidant properties of wheat varieties, milling methods, and food types

The interactions among wheat variety, milling method, and food type are shown in Fig. 1. As shown in Fig. 1-A, flour (without food processing) had higher TPC irrespective of wheat variety or milling method. In flour, the highest TPC value was obtained in the black wheat HBS (619.1–1811.6 μg GAE g⁻¹, mean: 1333.9 μg GAE g⁻¹) and the lowest TPC value was obtained in the white wheat YU (572.2–1436.8 μg GAE g⁻¹). Similar trends were observed with noodles. In steamed bread, black wheat HBS WWF had the highest TPC and other wheat varieties (SDZM and JZ) had lower TPC than YU. Interestingly, RF had the lowest TPC among all flours, and the TPC of RF was higher than that of noodles made from WWF, especially from white wheat YU. Compared with TPC of RF, TPC of noodles made from WWF decreased by 45.0%, 17.0%, 9.8%, and 10.8% for YU, SDZM, JZ, and HBS, respectively.

As shown in Fig. 1-B, colored wheat flour (with the exception of SDZM WWF and PGF) had higher TFC than did the white wheat YU. Similar trends were observed with noodles and steamed bread. Black wheat HBS flour had the highest TFC. Compared with the TFC of white wheat YU RF, white wheat WWF and PGF had higher TFC (5.6 times and 4.7 times, respectively). WWF and PGF were increased by 3.8 times and 3.8 times in SDZM, 7.9 times and 7.0 times in JZ, and 3.3 times and 2.9 times in HBS, respectively. Food processing significantly decreased TFC in flour irrespective of wheat variety or milling method. TFC of end-use products (noodles and steamed bread) was significantly lower than that of corresponding flours. However, the TFC values of noodles made from WWF, PGF, and TFC of RF were comparable. TFC in YU WWF noodles was 148.9 μg RE g⁻¹, while the corresponding value in RF was 146.8 μg RE g⁻¹. Steamed bread had lower TFC than flour and noodles.

### Table 3 – Antioxidant properties among different milling methods.

<table>
<thead>
<tr>
<th>Milling method</th>
<th>TPC (μg GAE g⁻¹)</th>
<th>TFC (μg RE g⁻¹)</th>
<th>ABTS⁺ (mmol L⁻¹ FeSO₄ g⁻¹)</th>
<th>FRAP (μmol L⁻¹ TE g⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WWF</td>
<td>744.7 a</td>
<td>376.1 a</td>
<td>10.3 a</td>
<td>44.4 a</td>
</tr>
<tr>
<td>PGF</td>
<td>618.9 b</td>
<td>325.3 b</td>
<td>9.8 b</td>
<td>35.1 b</td>
</tr>
<tr>
<td>RF</td>
<td>313.9 c</td>
<td>108.8 c</td>
<td>9.3 c</td>
<td>13.5 c</td>
</tr>
</tbody>
</table>

Means in the same column followed by different letters are significantly different (P < 0.05).

WWF, PGF, RF: whole wheat flour, partially debranned grain flour, and refined flour, respectively. TPC, TFC: total phenolic content and total flavonoid content, respectively.

### Table 4 – Antioxidant properties of different food types.

<table>
<thead>
<tr>
<th>Food type</th>
<th>TPC (μg GAE g⁻¹)</th>
<th>TFC (μg RE g⁻¹)</th>
<th>ABTS⁺ (mmol L⁻¹ FeSO₄ g⁻¹)</th>
<th>FRAP (μmol L⁻¹ TE g⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flour</td>
<td>1116.8 a</td>
<td>570.7 a</td>
<td>13.2 a</td>
<td>35.4 a</td>
</tr>
<tr>
<td>Noodle</td>
<td>334.3 b</td>
<td>154.2 b</td>
<td>7.5 c</td>
<td>29.9 b</td>
</tr>
<tr>
<td>Steamed bread</td>
<td>226.4 c</td>
<td>85.3 c</td>
<td>8.8 b</td>
<td>27.8 c</td>
</tr>
</tbody>
</table>

Means in the same column followed by different letters are significantly different (P < 0.05).

TPC, TFC: total phenolic content and total flavonoid content, respectively.
The FRAP assay results are shown in Fig. 1-C. The average FRAPs of flour were 42.3, 33.8, 31.7, and 33.7 mmol L \(^{-1}\) FeSO\(_4\) g \(^{-1}\) for HBS, JZ, SDZM, and YU, respectively. Black wheat WWF and PGF had significantly higher AOA than the other flour varieties. However, no significant differences were observed among WWF made from YU, JZ, or SDZM. Similar trends were observed with noodles and steamed bread. Compared with white wheat noodles, HBS noodles had higher FRAP values. In general, the highest FRAP value was obtained with WWF, followed by PGF and RF. Similar to TPC and TFC, FRAP was affected by the food processing. Compared with FRAP of white wheat YU flour, FRAP of white wheat noodles and steamed bread decreased by 13.7% and 19.2%, respectively. Similar results were obtained with colored wheat. Compared to HBS flour, black wheat noodle and steamed bread had lower FRAP values (−16.0% and −27.0%, respectively).

Similar results were obtained with the ABTS\(^{+}\) assay. Among the wheat varieties, HBS (mean: 13.2 \(\mu\)mol L \(^{-1}\) TE g \(^{-1}\)) had higher ABTS\(^{+}\) values in WWF (13.7 \(\mu\)mol L \(^{-1}\) TE g \(^{-1}\)) and PGF (13.4 \(\mu\)mol L \(^{-1}\) TE g \(^{-1}\)) than light purple or deep purple wheat flours. However, YU had significantly higher ABTS\(^{+}\) than the two purple wheat varieties (SDZM and JZ), which ranged from 12.5 to 13.3 \(\mu\)mol L \(^{-1}\) TE g \(^{-1}\). Similarly, ABTS\(^{+}\) values of noodles and steamed bread were reduced compared to those of flour. These results revealed that food processing reduces antioxidant activities. With similar milling methods, noodles had lower ABTS\(^{+}\) values than steamed bread. Thus, ABTS\(^{+}\) differences between noodles and steamed bread differed from the results obtained for TPC, TFC, and FRAP activity.

### 3.6. Correlation between TPC, TFC, and AOA

There were highly significant (\(P < 0.01\)) correlations between TPC and AOA (\(r = 0.769\) and \(r = 0.984\) for ABTS\(^{+}\) and FRAP, respectively) and between TFC and AOA (\(r = 0.726\) and \(r = 0.935\) for ABTS\(^{+}\) and FRAP, respectively) among the wheat flours (Table 5). Significant correlations were observed between TPC and AOA and between TFC and AOA in steamed bread. The
correlation between TPC and FRAP was significant ($r = 0.842$, $P < 0.01$) in noodles. However, no significant correlations were observed between TPC and ABTS$^+$ in noodles. The positive correlations between TPC and AOA and between TFC and AOA indicated that increasing the antioxidant content of wheat flour improves its AOA.

4. Discussion

Black-grained wheat refers to wheat varieties with black or purple seed coats. In recent years, black wheat has become popular among certain populations. Black-grained wheat has been reported to have higher TPC than white varieties [15]. Zong et al. [16] reported that blue, black-purple, and purple wheat grains have significantly higher antioxidant content than white or red wheat grains. In the present study, we found that all colored wheat varieties had higher TPC than white wheat. However, purple wheat JZ and SD$^2$M had lower TFC and antioxidant capacity than white wheat YU, indicating that colored wheat varieties do not consistently have higher AOA than white wheat. Similar results were obtained by Liu et al. [17], who reported that purple wheat Charcoal had high antioxidant activity, followed by red Red Fife and yellow Luteus varieties; however, purple wheat “Indigo” had lower antioxidant activity (as oxygen radical absorbance capacity) than white wheat AC Vista from Denmark. These results may be attributed to the wheat varieties, which contain different phenolic and flavonoid compounds. Oomah and Mazza [29] reported that the most abundant anthocyanins were cyanidin in red wheat, petunidin and malvidin in purple wheat, and delphinidin in blue wheat. Even the grain color gene ($R$) is involved in the activation of the early flavonoid biosynthesis gene [30]. A previous study also showed that there are many kinds of polyphenols in plant, and different phenolic molecular structures showed different antioxidant activities [31]. The relationship between grain color and antioxidant activity (including major genes controlling grain antioxidant activity) needs to be further studied and more wheat varieties of high AOA should be identified. The present study suggests that black wheat “HBS”, which is rich in antioxidants, can be used in health food production.

Active compounds are present mostly in the seed aleurone layer, and the removal of the bran and germ reduces the AOA of wheat [7,4]. Beta et al. [32] observed that TPC is concentrated in fractions from the first pearling and second pearling (wheat was initially stripped to remove 5% of the original kernel weight, resulting in a first fraction; the remaining kernel was then stripped to remove a second fraction of 5%). In this study, the highest antioxidant properties, including TPC, TFC, and AOA (ABTS$^+$ and FRAP), were obtained for WWF and the lowest antioxidant properties were obtained for RF, which was devoid of bran and germ. These results were in agreement with the findings of Hung et al. [33], who reported that total flavonoid content increased from the inner to the outer fractions. Thus, WWF and PGF should be recommended for improved human health. Similarly, Yu et al. [34] reported that whole wheat flour and bread had in vitro antioxidant properties superior to those of refined flour and bread.

Food processing including mixing, kneading, and heating affects the antioxidant properties of foods. Chlopicka et al. [12] reported that TFC of flours was approximately 2 to 4 times higher than that of breads. In the present study, TPC, TFC, and AOA decreased following food processing, in accord with the findings reported by Zhang et al. [35]. The reduction in antioxidants was likely due to the loss of phenolic acids during food processing [12]. Two food types (noodle and steamed bread) reduced TPC. However, the TPC reduction from flour to steamed bread was higher than that from flour to noodles. It has been reported that antioxidant compounds present in flour are damaged or degraded by thermal treatment [36]. Similarly, antioxidants are lost during dough mixing and kneading [12]. In this study, noodle making and steamed bread making involved dough mixing and kneading. The difference in AOA between noodles and steamed bread may be attributed to the cooking method: noodle making involves boiling water and steamed bread making involves steam. Dietrichy-Szostak and Oleszek [37] reported that the flavonoid content of buckwheat decreased by 20% following milk heat treatment and by 75% following severe heat treatment. In the present study, the reduction in TFC of noodles and steamed bread was approximately 80% relative to that of flour. The reduction in TFC may be due to flavonoid breakdown during heating and/or extraction of glycosides by steam (especially for steamed bread) [34]. However, ABTS$^+$ values were lower in noodles than in steamed bread, a result different from those obtained for TPC, TFC, and FRAP, probably owing to the different test methods. Additionally, it is possible that different flavonoids and phenolic compounds in flour respond differently to food processing. The changes in phenolic and flavonoid compounds from flours to food products await further evaluation.

5. Conclusion

TPC, TFC, and AOA of whole wheat flour were higher than those of commercial refined flour. Food processing methods affected TPC and AOA. Antioxidants decreased in noodle and steamed bread compared with flour. Black wheat Heibaoshi 1 had the highest TPC, TFC, and AOA. The consumption of whole black wheat flour may be beneficial to human health.

Acknowledgments

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