Physico-Chemical and Functional Properties of Nano and Fermented-Nano Powders of Some Food Plant By-products

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ABSTRACT

Nano and fermented-nano powders of five food by-products were prepared by superfine grinding of raw and fermented materials. Effects of fermentation and superfine grinding on the chemical, physical and functional properties of the fiber products were investigated. The results showed that superfine grinding could effectively pulverize the fiber particles to nano-scale. Chemical analysis revealed higher protein content (33.98%) in wheat germ, higher fat (8.97%) and ash (8.27%) contents in rice bran and higher fiber content (56.66%) in pomegranate peels. These components were significantly affected by fermentation and ultrafine grinding. Color investigation showed higher lightness value (74.02) for wheat bran, higher redness value (14.24) for pomegranate peels and higher yellowness value (32.53) for wheat germ. The reduction in particle size has a significant effect on the color attributes of tested samples. Higher values of lightness and lower values of redness, as well as color differences were noticed in nano-materials than conventional materials. Carrot pomace has the highest water holding capacity (7.49 g/g), as well as swelling capacity (6.12 ml/g). Pomegranate peels has the highest water solubility index (22.55%) while, wheat germ has the highest emulsifying activity (60.67%). As particle size decrease, the functional properties were significantly (p<0.05) affected. The water and oil holding capacity decreased, while swelling capacity, water solubility index and emulsifying activity increased. These results indicated that these materials have potential to be utilized as functional ingredients in foods.

Key words: Food by-products, solid-state fermentation, nanotechnology, functional properties

Introduction

Agricultural or forestry refuses including cereal and vegetable wastes such as straw, bagasse, stover, cobs, husks, among others, are lignocellulosic materials composed mainly of cellulose, hemicelluloses and lignin. (Mussatto et al., 2007). Consumption of high fiber products consisting of such materials has several health benefits (Sudha, et al., 2007). So, in recent years, dietary fiber has received increasing attention from researchers and industry due to the likely beneficial effects on coronary heart disease (Streppel et al., 2008), stroke (Larsson, 2014), hypertension (Zhou et al., 2015), diabetes (Kuijsten, 2015), obesity (Kranz et al., 2012) and certain gastrointestinal disorders (Eswaran et al., 2013). Furthermore, increased consumption of dietary fiber improves immune function (Zhao et al., 2015) and colon cancer (Hu et al., 2009; Rodriguez et al., 2006; Scheppach et al., 2004; Abdul-Hamid and Luan, 2000). In addition to nutritional effects, fibers have functional properties such as water binding capacity, swelling capacity, oil binding capacity and emulsifying activity. So, Addition of dietary fiber to a wide range of products will contribute to the development of value-added foods or functional foods that currently are in high demand for consumers (Quershi et al., 2002; Pacheco et al., 2005; Parrado, et al. 2006; Hu et al., 2009; Kohajdova et al. 2012; Viuda-Martos et al. 2012) also, it can give these functional properties to the foods (Fadaei and Salehifar, 2012). But fibers may confer unwanted properties to foods in terms of processing or acceptability by consumers. This is related to the intrinsic properties of the tissues or of their components. There is therefore a need for a processing technology that can efficiently produce new ingredients with optimized techno-functional and nutritional attributes (Hemery et al., 2007).

This could be achieved using aqueous phase chemical, enzymatic, and/or fermentation methods. Solid-state fermentation, however, offers the advantages of being low cost, more energy-effective and more environmental friendly (Krishna, 2005). Of the reported potential microorganisms for solid-state treatments, Saccharomyces cerevisiae is a particularly attractive option given its generally regarded as safe (GRAS) status for food products (Grange et al., 1996). In addition, S. cerevisiae can grow under lower water activities than bacteria which if growing could pose a food safety issue. Together, these factors suggest the possibility that solid-state yeast treatments may lead to a product rich in natural antioxidants and dietary fiber, and enhanced protein levels (Krishna, 2005).

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Also, the possible use of micro- or nanotechnology in food research has attracted much attention, and become the focus of research in many countries (Zhu et al., 2010). Superfine powders are easier to incorporate into food structure and for absorption by the body, which would consequently improve the quality and safety of food products and human health. (Raghavendra et al., 2004). However, so far the use of this technology in fibers processing remains rather limited, probably due to the toughness and polymer nature of fibers and inadequate equipment support (Zhu et al., 2010). Several techniques were used to reduce the particle size. For example, rotor mill, impact mill and jet-mill (Noort et al., 2010), dry ambient and dry cryogenic ultrafine grinding techniques (Hemery et al., 2011) and multidimensional swing high-energy nano-ball-milling (Zhu et al., 2010). Also, many investigators studied the effect of ultrafine grinding and particle size on functional properties such as water holding capacity, water solubility index and swelling capacity (Ming et al., 2015; Chau et al., 2007; Zhao et al., 2009).

The aim of this study was to apply modern techniques including, solid-yeast treatment and superfine grinding, to modify the structure of tested food by-products that used in food products. Also, the effects of these methods on physic-chemical and functional properties of tested food by-products were investigated.

Materials and Methods

Materials:
Wheat bran (particle size >1.68 mm) and wheat germ were obtained from North Cairo Flour Mills Company, Egypt. Rice bran was obtained from Rice Research and Training Centre, Sakha, Kafr El-Sheikh, Egypt. Carrot (Daucus carota) and full ripened pomegranate fruits (Punica granatum L.) were purchased from the local market, Giza, Egypt during 2013/2014. Other chemicals used in this study for chemical analysis were of analytical grade.

Methods:
Preparation of raw materials:
Stabilization of wheat germ and rice bran:
Wheat germ and rice bran were stabilized in an air-oven at a temperature of 120±2°C for 1min according to Younas et al. (2011). The stabilized wheat germ and rice bran were ground using Moulinex grinder and passed through a 40-mesh and packed in polyethylene bags and stored at -30 °C until use.

Preparation of carrot pomace:
Carrot pomace was obtained after juice extraction (Juice extractor, Moulinex 753, Mexico). Carrot pomace obtained after juice extraction was dried in an air-oven at 50±1°C for 16h. The dried sample was ground using Moulinex grinder and passed through a 40-mesh sieve and packed in polyethylene bags and stored at -30 °C until use.

Preparation of Pomegranate peel:
The peel of pomegranate was manually removed and dried in an air-oven at 50±5°C for 16h. The dried sample was grounded using Moulinex grinder and passed through a 40-mesh sieve and packed in polyethylene bags and stored at -30 °C until use.

Solid-state yeast fermentation:
Yeast strain (Saccharomyces cerevisiae FC-620) was obtained from Microbial Chemistry Dept. collection, National Research Centre, Dokki, Giza, Egypt. The yeast cells were activated, a loopful of the culture was transferred to 250 ml Erlenmeyer flask containing 50 ml broth medium (0.3% yeast extract, 0.3% malt extract, 0.5% peptone and 5% sucrose) and incubated at 30 °C for 24h under shaking condition. Solid-state yeast treatments were carried out according to the method of Moore et al. (2007) as follows: 50ml of yeast preparation (1380 cfu/ml) was mixed with 100g fiber sample in a sterile conical flask (1000 ml) to begin the solid-state yeast treatment. Flasks were sealed with cotton seals and incubated at 37°C for 48h. All treated samples were dried at 50±1°C for 16h and stored in polyethylene bags at -30°C for further analysis.

Preparation of nano and fermented-nano materials:
The raw and fermented wheat bran, wheat germ, rice bran, carrot pomace and pomegranate peels were ground using 5 ml zirconium oxide balls and zirconium oxide bowl volume 250 ml in a PM 100 Planetary Ball-mill (Retsch, Germany) as described by Zhu et al. (2010) with some modifications. Samples (150 g) were ground at 30 Hz frequency for 60 min at room temperature (25°C).
Transmission Electron Microscopy:
All ground samples were examined with a JEOL JX 1230 technique with micro analyzer probe, Japan. This technique was used to determine the particle size of the investigated samples.

Color measurements:
The color of raw, nano and fermented-nano materials was measured using a spectrophotometer with the CIE color scale (Hunt, Lab scan XE) (Commission Internationale de l’Eclairage (CIE), 1976). This instrument was standardized against the white tile of Hunter Lab color standard (LX No.16379): X= 77.26, Y= 81.94 and Z= 88.14. The L, a and b values were reported. Total color difference (ΔE) was calculated as:

\[ \Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \]

Chemical composition:
Moisture, protein (N x5.71), lipids (ether extract), ash and crude fiber contents were determined according to AOAC (2000). Available carbohydrate was determined by dinitrosalicylic acid method according to BeMiller (2010).

Functional properties:
Water holding capacity:
Water holding capacity (WHC) was determined according to the method developed by Zhang (2005). Cleaned centrifuge tubes were weighed (W). Half gram (W1) of each sample and 7 mL distilled water were then poured into the centrifuge tubes. The tubes were incubated in a water bath at 60 °C for 30 min and then placed in cold water for 30 min. The tubes were centrifuged at 2683 g for 15 min. Afterward, the supernatant was removed and the centrifuge tubes containing the sediment (W2) were weighed again. WHC was calculated as follows:

\[ \text{WHC (g/g wet sample)} = \frac{(W2 - W)}{W1}. \]

Swelling capacity:
Swelling capacity (SC) was determined according to the method developed by Lecumberri et al. (2007). One gram (M) of the samples was accurately weighed and poured into a 25mL calibrated cylinder. The initial volume (V1) was recorded. The samples were then mixed with 20 mL of distilled water and shocked manually for 5 min. Afterwards, they were placed into a water bath at 25°C for 24 h. The volumes of the samples (V2) were recorded again. Finally, SC was calculated using the following formula:

\[ \text{SC (mL/g wet sample)} = \frac{(V2 - V1)}{M}. \]

Water solubility index:
Water solubility index (WSI) was measured according to the method of Zhao (2009). Samples (W1) were dispersed in a centrifuge tube at ambient temperature (25 °C) by adding water at a powder/water ratio of 0.02/1 (w/w). The dispersed powders were then incubated in a water bath at 80 °C for 30 min, followed by centrifugation at 6037 g for 10 min. The supernatant was carefully collected in a pre-weighed evaporating dish (W2, g) and dried at 105±1°C for 2h. The evaporating dish containing the residue was then weighed once more (W3, g). WSI was calculated as follows:

\[ \text{WSI (%)} = \frac{(W3 - W2)}{W1} \times 100\%. \]

Oil holding capacity:
Oil holding capacity (OHC) was measured according to the method described by Abdul-Hamid and Luan (2000). Four grams (M) of the samples was added to 20 mL maize oil (V1) in a 50 mL centrifuge tube. The content was stirred for 30 s every 5 and 30 min. The tube was centrifuged at 1499 g for 25 min. The free oil (V2) was decanted, and the absorbed oil was measured. OHC was calculated as follows:

\[ \text{OHC (mL/g wet sample)} = \frac{(V1 - V2)}{M}. \]

Emulsifying activity and emulsion stability:
Emulsifying activity (EA) and emulsion stability (ES) were determined according to the method of Chau et al. (1997) as follows: 100 ml of 2% (w/v) sample suspension in water was homogenized for 30s then, 100 ml of sunflower oil was added and homogenized for another 1min. The emulsions were centrifuged in 10mL graduated centrifuge tubes at 1200 g for 5min, and the volume of the emulsion left was measured. The EA was calculated as:

\[ \frac{\text{Volume of emulsified layer}}{\text{Volume of whole layer}} \times 100 \]
To determine the ES, emulsions prepared by the above procedures were heated at 80°C for 30 min, cooled to room temperature (25 °C), and centrifuged at 1200 g for 5 min. The ES was calculated as:

\[
\frac{\text{Volume of remaining emulsified layer}}{\text{Volume of emulsified layer}} \times 100
\]

Statistical Analysis

All samples were analyzed in triplicates and the results were expressed as means ± standard error. Statistical analysis was assessed using the software SAS System for Windows (Statistical Analysis System) (2008). The significant difference between the mean values were determined by using the analysis of variance (ANOVA) and Duncan’s multiple range test was conducted at a significance level of p<0.05.

Results and Discussion

Particles size analysis

Transmission Electron Microscopy technique (TEM) was used to determine the particle size of raw and fermented wheat bran (WB), wheat germ (WG), rice bran (RB), carrot pomace (CP) and pomegranate peels (PP). The TEM micrographs of these samples are shown in Fig. (1). The TEM images gave a detailed view of the particle size and morphology of tested materials. The particles size of the WB, WG, RB, CP and PP was distributed in a range from 10-21, 7-19, 15-47, 8-58, 21-35 nm, respectively, which indicated that they are in the nano-scale. In addition, a limited amount of the particles of fermented materials were found agglomerated (Fig. 1 c, e, h and j). These results revealed that pulverization by high-energy ball-milling could effectively reduce the sizes of the particles to a nano-scale; and it was thus feasible to utilize this technique to prepare ultrafine powder.

Zhu et al. (2010), used ultrafine ball milling to decrease the particle size of wheat bran by using multidimensional swing high-energy nano-ball-milling with ZrO2 balls (6-10 mm in diameter). After ultrafine milling, the average particle size was \(D_{30} = 344\) nm. They mentioned that, for wheat bran used as filler particle in food applications, this kind of ultrafine milling technology would not be cost-effective. Nevertheless, the study showed that the particle size can be reduced under the sub-micron level.

Chemical composition of raw, nano and fermented-nano materials

The results of chemical analysis of investigated raw materials used in the present work before and after grinding, as well as fermented nano-materials are shown in Table (1). Protein contents of tested materials showed significant differences (p<0.05) being 4.21% for PP and reached 33.98% for WG. Other raw materials displayed intermediate values being 7.93% for CP and 15.59% for WB. With respect to lipid content, all samples had low lipid content except RB (8.97%) followed by WG (7.69%). There were no significant differences between the lipid contents of CP and PP (0.98 and 0.52%, respectively). Remarkable high ash content was noticed for all samples. The highest ash percentage was found in the RB (8.27%) followed by PP (6.40%). Crude fiber content of PP (56.66%) was significantly higher than those of other tested materials, while WG had the lowest value (11.11%). Data in the same table proved minimum carbohydrate content for PP (32.20%) and maximum for WB (54.30%). Similar results were reported by Majzoobi et al. (2012); Srivastava et al. (2007); Faria et al. (2012); Shyamala and Jamuna (2010) and Kohajdova et al. (2012) for wheat bran; wheat germ; rice bran, carrot pomace and pomegranate peel, respectively. While, Viuda-Martos et al. (2012) reported higher protein (10.9%) and fat (20.9%) and lower ash (2.5%) contents for whole pomegranate bagasse this may be due to the presence of arils bagasse.

On the other hand, superfine grinding of RB to nano-scale significantly decreased protein, fat and ash contents from 8.81, 8.97 and 8.27% to 7.96, 8.03 and 7.92%, respectively (Table 1). There were no significant differences in protein, fat and ash contents of other nano-materials as compared to raw materials. Crude fiber content of nano- materials decreased as a result of particle size reduction while, available carbohydrates were increased (Table 1). Zhu et al. (2010) found that insoluble dietary fiber of wheat bran decreased from 81.13% to 68.65% while soluble dietary fiber increased from 2.90% to 11.47% after grinding, suggesting that ultrafine grinding causes a redistribution of fiber components from the insoluble to the soluble fractions. The fermentation of tested materials significantly increased protein content of all samples except RB. However the available carbohydrates showed a reversible trend with the protein. These results could be attributed to the growth of yeast.
Fig. 1: Transmission electron micrographs of nano and fermented-nano-powder: wheat bran (a,b); wheat germ (c,d); rice bran (e,f); carrot pomace (g,h); pomegranate peel (i,j).
Table 1: Proximate chemical composition of raw, nano and fermented-nano-materials (% on dry weight basis)a

<table>
<thead>
<tr>
<th>Samples</th>
<th>Constituents</th>
<th>Protein (N×5.71)</th>
<th>Lipids</th>
<th>Ash</th>
<th>Crude fiber</th>
<th>Available carbohydrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>WB</td>
<td>15.59f ± 0.22</td>
<td>2.16f ± 0.06</td>
<td>4.24f ± 0.02</td>
<td>23.70f ± 0.30</td>
<td>54.30f ± 0.09</td>
<td></td>
</tr>
<tr>
<td>NWB</td>
<td>15.72e ± 0.01</td>
<td>2.67e ± 0.06</td>
<td>4.54e ± 0.07</td>
<td>23.63e ± 0.48</td>
<td>53.44e ± 0.62</td>
<td></td>
</tr>
<tr>
<td>FNWB</td>
<td>18.997 ± 0.02</td>
<td>2.277 ± 0.03</td>
<td>4.347 ± 0.07</td>
<td>23.717 ± 0.11</td>
<td>50.687 ± 0.25</td>
<td></td>
</tr>
<tr>
<td>WG</td>
<td>33.987 ± 0.31</td>
<td>7.467 ± 0.47</td>
<td>5.297 ± 0.08</td>
<td>11.117 ± 0.07</td>
<td>42.197 ± 0.74</td>
<td></td>
</tr>
<tr>
<td>NWG</td>
<td>34.367 ± 0.22</td>
<td>7.6932 ± 0.43</td>
<td>4.8370 ± 0.03</td>
<td>7.000 ± 0.52</td>
<td>46.123 ± 0.05</td>
<td></td>
</tr>
<tr>
<td>FNWG</td>
<td>39.337 ± 0.17</td>
<td>6.3230 ± 0.20</td>
<td>4.6800 ± 0.10</td>
<td>23.6411 ± 0.78</td>
<td>26.031 ± 1.15</td>
<td></td>
</tr>
<tr>
<td>RB</td>
<td>8.817 ± 0.42</td>
<td>8.9730 ± 0.34</td>
<td>8.274 ± 0.06</td>
<td>38.9247 ± 0.46</td>
<td>35.034 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>NRB</td>
<td>7.9670 ± 0.13</td>
<td>8.0360 ± 0.31</td>
<td>7.928 ± 0.05</td>
<td>34.9210 ± 0.25</td>
<td>41.188 ± 0.57</td>
<td></td>
</tr>
<tr>
<td>FNRB</td>
<td>8.697 ± 0.11</td>
<td>8.3830 ± 0.11</td>
<td>7.558 ± 0.19</td>
<td>38.8637 ± 0.10</td>
<td>36.519 ± 0.12</td>
<td></td>
</tr>
<tr>
<td>CP</td>
<td>7.9307 ± 0.09</td>
<td>0.987 ± 0.10</td>
<td>5.347 ± 0.09</td>
<td>37.454 ± 0.49</td>
<td>48.317 ± 0.25</td>
<td></td>
</tr>
<tr>
<td>NCP</td>
<td>8.3907 ± 0.02</td>
<td>1.157 ± 0.03</td>
<td>5.477 ± 0.01</td>
<td>40.906 ± 0.38</td>
<td>44.107 ± 0.54</td>
<td></td>
</tr>
<tr>
<td>FNCP</td>
<td>9.907 ± 0.06</td>
<td>0.967 ± 0.29</td>
<td>5.0170 ± 0.28</td>
<td>43.4373 ± 0.34</td>
<td>40.717 ± 1.17</td>
<td></td>
</tr>
<tr>
<td>PP</td>
<td>4.217 ± 0.06</td>
<td>0.527 ± 0.48</td>
<td>6.407 ± 0.12</td>
<td>56.6647 ± 1.99</td>
<td>32.207 ± 1.54</td>
<td></td>
</tr>
<tr>
<td>NPP</td>
<td>5.857 ± 0.01</td>
<td>1.067 ± 0.12</td>
<td>6.667 ± 0.04</td>
<td>51.085 ± 0.14</td>
<td>35.3537 ± 0.10</td>
<td></td>
</tr>
<tr>
<td>FNPP</td>
<td>7.627 ± 0.02</td>
<td>0.757 ± 0.29</td>
<td>6.597 ± 0.09</td>
<td>61.674 ± 0.86</td>
<td>23.374 ± 0.56</td>
<td></td>
</tr>
</tbody>
</table>

aValues in the same row followed by different letters are significantly different (p < 0.05)

bWB- wheat bran, NWB- nano-wheat bran, FNWB- fermented-nano- wheat bran, WG- wheat germ, NWG- nano-wheat germ, FNWG-fermented-nano-wheat germ, RB- rice bran, NRB- nano-rice bran, FNWB-fermented-nano-rice bran, CP- carrot pomace, NCP- nano-carrot pomace, FNCP-fermented-nano-carrot pomace, PP- pomegranate peel, NPP- nano-pomegranate peel, FNPP-fermented-nano-pomegranate peel

Color quality as affected by fermentation and ultrafine grinding

Color attributes of raw, nano and fermented-nano-materials are shown in Table (2). There were significant differences between all tested samples (p < 0.05). L values of the tested materials ranged from 36.16 to 77.29. The highest value was recorded to NWB while, the lowest value was recorded to PP. Also, there were significant differences between raw and nano-forms of all tested samples. Ultrafine grinding increased L values of all tested samples. The highest increment was noticed in PP as the L value increased from 36.16 to 60.50 for NPP. This could be attributed to the distribution of pigments in the outer and inner layers of tested samples. On the other hand, L values of fermented nano-materials were decreased compared to nano-materials. The highest decrements were recorded to NCP and NPP as they decreased from 70.49 and 60.50 to 54.73 and 47.99 for FNCP and FNPP, respectively. This could be due to the enzymatic browning during fermentation process.

As regards the red–green coordinate "a", reversed trends to L values were noticed. Higher value of redness was noticed in PP than other tested materials. The higher "a" values may be attributed to the presence of the red to brown pigments naturally existing in the peels. Ultrafine grinding decreased "a" values of all tested materials. Also, "a" values of fermented nano-materials showed opposite trend to L values as they increased compared to raw and nano-forms of all tested materials. This could be due to the enzymatic browning during fermentation process. This coordinate is affected by the structural integrity of the fiber and the pigment content and disposition (water or lipid-soluble) (Fernandez-Lopez et al., 2005).

The tested materials presented yellowness (b values) ranged from 19.09 to 32.53. WG and CP tended to have higher "b" values compared to other materials. These high b values could be due to the carotenoids present in the mentioned samples. The effect of ultrafine grinding on "b" values of tested materials showed different trends compared to L and "a" values. Ultrafine grinding of cereal materials (WB, WG and RP) significantly decreased "b" value while, ultrafine grinding of CP and PP significantly increased "b" value. This could be attributed to the distribution of yellow pigments in the outer and inner layers of tested samples.

In conclusion, the reduction in particle size of raw materials has a significantly effect on the color attributes of the tested materials. Higher values of lightness and lower values of redness, as well as total color differences were noticed in nano-materials than the conventional material. Since the reduction of particle sizes might cause the release of some pigments naturally present in the different layers of materials.

Viuda-Martos et al. (2012) revealed that whole pomegranate bagasse (WPB) and arils bagasse (AB) presented L values of 62.82 and 62.23, "a" values of 7.3 and 6.8 and "b" values of 17.3 and 10.6 respectively. They attributed the high "b" value to the carotenoids present in the pomegranate bagasse fiber, which were not
eliminated by washing. Color properties of AB and WPB samples showed their suitability as an ingredient in a large variety of food products, especially in meat and fish products, which may mask AB and WPB color.

Table 2: Color attributes of raw, nano and Fermented-nano materials.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Attributes</th>
<th>Lightness (L)</th>
<th>Redness (a)</th>
<th>Yellowness (b)</th>
<th>Total color differences (ΔE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WB</td>
<td></td>
<td>74.02±0.037</td>
<td>4.88±0.067</td>
<td>19.83±0.078</td>
<td>27.80±0.048</td>
</tr>
<tr>
<td>NWB</td>
<td></td>
<td>77.29±0.11</td>
<td>3.78±0.04</td>
<td>18.03±0.13</td>
<td>24.16±0.17</td>
</tr>
<tr>
<td>FNWB</td>
<td></td>
<td>68.43±0.30</td>
<td>5.61±0.08</td>
<td>24.68±0.07</td>
<td>35.19±0.25</td>
</tr>
<tr>
<td>WG</td>
<td></td>
<td>67.29±0.24</td>
<td>5.43±0.11</td>
<td>32.53±0.63</td>
<td>41.75±0.59</td>
</tr>
<tr>
<td>NWG</td>
<td></td>
<td>74.16±0.11</td>
<td>3.74±0.03</td>
<td>29.59±0.10</td>
<td>35.24±0.13</td>
</tr>
<tr>
<td>FNWG</td>
<td></td>
<td>70.09±0.11</td>
<td>6.40±0.03</td>
<td>28.44±0.14</td>
<td>37.05±0.18</td>
</tr>
<tr>
<td>RB</td>
<td></td>
<td>63.13±0.20</td>
<td>6.46±0.04</td>
<td>22.95±0.11</td>
<td>38.08±0.22</td>
</tr>
<tr>
<td>NRB</td>
<td></td>
<td>66.08±0.05</td>
<td>5.52±0.04</td>
<td>20.72±0.13</td>
<td>34.27±0.12</td>
</tr>
<tr>
<td>FNRB</td>
<td></td>
<td>57.66±0.10</td>
<td>6.32±0.03</td>
<td>21.29±0.09</td>
<td>41.54±0.12</td>
</tr>
<tr>
<td>CP</td>
<td></td>
<td>61.47±0.52</td>
<td>8.94±0.16</td>
<td>26.38±0.21</td>
<td>41.99±0.46</td>
</tr>
<tr>
<td>NCP</td>
<td></td>
<td>70.49±0.58</td>
<td>7.27±0.32</td>
<td>28.23±0.47</td>
<td>36.82±0.78</td>
</tr>
<tr>
<td>FNCP</td>
<td></td>
<td>54.73±0.68</td>
<td>7.37±0.21</td>
<td>22.94±0.21</td>
<td>45.03±0.72</td>
</tr>
<tr>
<td>PP</td>
<td></td>
<td>36.16±0.29</td>
<td>14.24±1.00</td>
<td>20.70±0.12</td>
<td>61.97±0.41</td>
</tr>
<tr>
<td>NPP</td>
<td></td>
<td>60.50±0.09</td>
<td>10.07±0.01</td>
<td>29.62±0.02</td>
<td>45.05±0.07</td>
</tr>
<tr>
<td>FNPP</td>
<td></td>
<td>47.99±0.75</td>
<td>6.94±0.14</td>
<td>19.09±0.11</td>
<td>49.12±0.73</td>
</tr>
</tbody>
</table>

*Values in the same column followed by different letters are significantly different (p<0.05)


Functional properties as affected by fermentation and ultrafine grinding

Hydration properties

Hydration properties such as water holding capacity (WHC), swelling capacity (SC) and water solubility index (WSI) of raw materials and the effect of fermentation, as well as ultrafine grinding were measured and presented in Fig. (2). WB, WG, RB, CP and PP exhibited WHC values of 4.21, 2.70, 3.48, 7.49 and 3.70 times its own weight, respectively. Vlada-Martos et al. (2012) mentioned that water-holding capacity is related to the soluble dietary fiber (SDF) content, and high levels of SDF produce a high WHC value. This could be explained by the higher WHC of soluble fibers, such as pectin and gums than cellulosic fibers. So, the higher WHC of CP could be due to the chemical structure as it known that CP contains more pectic substances, which possess a higher WHC than cellulosic fibers in cereal by-products. All the tested samples showed decreased WHC after the grinding treatment. As shown in Fig. (2), WHC values were reduced to 3.62, 2.15, 2.49, 4.84 and 2.83 for NWB, NWG, NRB, NCP and NPP, respectively. Such effects could be attributed not only to particle size reduction, but also to the altering of the fiber matrix structure. This could be explained according to Kethiredipalli et al. (2002). They reported that WHC depends on porous matrix structure formed by polysaccharide chains which can hold large amounts of water through hydrogen bonds. Also, Sangmark and Noonhorm (2003) reported that particle size reduction of dietary fibers has been associated with a lower ability to retain water and a lower oil binding capacity.

On the other hand, the swelling capacity of CP (6.12 ml/g) was also significantly higher than those of other tested materials, followed by WG (3.59 ml/g). But the SC values of nano and fermented-nano materials were slightly higher than those of raw materials (Fig. 2b). PP and WG had the highest WSI values (22.53 and 19.72%, respectively), which refers to the amount of food constituents that are released from a complex food matrix to water. WSI of nano materials were significantly higher than those of raw materials (Fig. 2c). The increase in WSI reached the maximum for NPP followed by NWG (35.97 and 30.38%). According to Ming et al. (2015) the increase in WSI and SC could be explained by the breaking of the long cellulose chains by superfine grinding into many short cellulose chains. These chains swell to enlarge the space. Also, superfine grinding enhanced the exposure probability of the hydrophilic cellulose and hemicellulose groups. This enhanced exposure increases the WSI and SC of the powders.

The results indicated that the particles size of samples plays an important role in determining its hydration properties such as WHC, SC and SCI. There are some reports presenting the similar phenomena, apart from these studies, Zhu et al. (2010) and Ming et al. (2015) reported that ultrafine grinding cold effectively pulverize
the fiber particles to submicron scale. As particle size decrease, the hydration properties (water holding capacity, water retention capacity and swelling capacity) were significantly (p < 0.05) decreased and redistribution of fiber components from insoluble to soluble fraction was observed.

![Water Holding Capacity (g/g)](image1)

![Swelling capacity (ml/g)](image2)

![Water solubility index (%)](image3)

Fig. 2: Hydration properties of raw, nano and fermented-nano materials.

Oil-holding capacity and emulsifying properties

The tested materials showed an OHC ranged from 0.92 to 2.47 ml oil/g sample. WB has the highest value, while the lowest value was recorded to both NWG and FNCP as shown in Fig. (3a). Ultrafine grinding decreased the OHC of all tested samples except NPP. Same findings were noticed when fermented nanomaterials were considered. For instance, The OHC of FNWB that was 2.47 ml/g being 1.23 ml/g for raw WB. This could be due to the porous matrix structure formed by polysaccharide chains which can hold large amounts of oil through hydrogen bonds (Kethireddipalli, et al. 2002).

![Figure (3): Oil holding capacity and emulsifying properties of raw, nano and fermented-nano materials (ml/100ml).](image)

FNWG had the highest EA value, while PP had the lowest EA (61.59 and 35.33 ml/100 ml, respectively). EA values of other tested samples varied in narrow range from 53.94 to 60.67 ml/100 ml as illustrated in Fig. (3b). Except PP, fermentation and ultrafine grinding did not significantly affect the EA of all tested samples. The high protein content of WG sample would explain its high EA (Table 1), since most proteins are strong emulsifying agents. On contrast, ES results showed opposite trend to EA results (Fig. 3). RB and PP had the highest values of ES (99.32, 97.25 ml/100 ml), while WB had the lowest ES value (28.70 ml/100 ml). Except WB and FNGW, fermentation and ultrafine grinding significantly decreased the ES values of all tested samples.

Conclusions
This study demonstrates that high energy ball milling can effectively reduce the particle sizes of tested food by-products to nano-scale. Color attributes showed that wheat germ and carrot pomace tend to be more yellow, so they may be considered a potential functional ingredient in pasta products. While, pomegranate peels tend to have red color, so it could be a potential functional ingredient in meat products which masked the darker color of pomegranate peel. Carrot pomace had the highest functional properties, as high swelling, water and oil holding and good emulsify and stability capacity. Ultrafine powders showed decreased water and oil holding ability and increased solubility, as well as swelling capacity. Functional properties study of fine by-products and their chemical composition reveals their suitability to be a good source of food fiber for human consumption and as consequence, a functional ingredient.

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References


