Thermal, textural and cooking properties of spaghetti enriched with resistant starch

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Abstract

Resistant starch type III (RS₃) was used to enrich spaghetti. It was compared to bran and control spaghetti with respect to cooking losses, water absorption, thermal and textural properties. Optimum cooking times were determined both by differential scanning calorimeter (DSC) and image analysis. Optimum cooking times were 12.5, 13, and 12 min for control, resistant starch (RS) and bran containing spaghetti, respectively. The onset and peak temperatures of gelatinisation were found 58 and 64 °C, respectively. Textural parameters were evaluated by TA-XT2i texture analyser and compared with the results of a sensory panel. The hardness and adhesiveness values of bran spaghetti were higher than the control and RS spaghetti. On the other hand hardness values of control and RS spaghetti were not so different. Cooking time-spaghetti type interactions were found to be significant for texture profile parameters (TPA) except chewiness. The effect of cooking time and spaghetti type on hardness, adhesiveness, cohesiveness, and chewiness during cooking was significant (p < 0.05). The results of TPA correlated well with the sensorial judgement of hardness, adhesiveness and cohesiveness.

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Keywords: Resistant starch; Spaghetti; Texture; DSC; Cooking quality

1. Introduction

In modern societies, great emphasis is frequently placed on the relationship between health, lifestyle and diet. As a result, today’s consumers are more aware of what they eat. But, it is still a fact that many individuals do not get the fibre their bodies need to work efficiently and feel comfortable. The significance of fibre and resistant starch for the prevention of civilisation related diseases causes us to pay more attention to materials rich in these components. Starch, which is the major dietary source of carbohydrates, is the most abundant storage polysaccharide in plants, and occurs as granules in the chloroplast of green leaves and the amyloplast of seeds, pulses and tubers. The relatively recent recognition of incomplete digestion and absorption of starch in the small intestine as a normal phenomenon has raised interest in nondigestible starch fractions. These are called “resistant starches”, and extensive studies have shown them to have physiological functions similar to those of dietary fiber (Brighenti, Casiraghi, & Baggio, 1998; Haralampu, 2000; McCleary & Monaghan, 2002; Sajilata, Singhal, & Kulkarni, 2006; Thompson, 2000). Several metabolites can be formed like short chain fatty acids acetate, butyrate and propionate with potential beneficial health effects (Liljeberg, Akerberg, & Björck, 1996). Certain food processing methods, such as retorting, baking or drying at high temperatures, are known to slightly increase RS levels. Processes like boiling may cause starch to loose its resistance. Resistant starch, which is a natural component that is present in many foods, has a role to play with regard to the nutritional benefits of fibre fortification. It goes under many definitions but, in essence, it is starch that is resistant to digestion in the stomach and small intestine. Resistant starch offers advantages over cellulosic sources of fibre such as bran. It provides low water holding capacity thereby aiding processing; it enhances the organo-
Resistant starch can be divided into three sub-categories:

RS$_1$: physically trapped starch as found in coarsely ground or chewed cereals, legumes and grains. For RS$_1$ to be digested, the seed or outer coating must be broken such that the starch granules are no longer entrapped.

RS$_2$: RS granules or nongelatinized starch granules, which are highly resistant to digestion by $\alpha$-amylase until gelatinised (uncooked potato, green banana, and high amylose starch).

RS$_3$: Retrograded starch polymers; mainly amylose, which are produced when starch is cooled after gelatinization (McCleary & Monaghan, 2002; Thompson, 2000). RS$_3$ is present in bread, cooked and cooled potatoes, and ready to eat breakfast cereals in which the starch has been cooked and retrograded by processing (Manthey, Yalla, Dick, & Badaruddin, 2004).

Among the resistant starches RS$_3$ seems to be more interesting. As mentioned above it contains mainly retrograded amylose with a melting temperature of 150°C. This property makes RS$_3$ an appropriate candidate as a heat-stable pre-biotic food additive, which may be used in cooked or baked goods (Shamai, Bianco-Peled, & Shimoni, 2003).

Pasta and its products are the main subgroup of many diets. In fact there are bran containing pasta products in the market; consumers still do not like to include these products into their diet because of many organoleptic and textural reasons such as colour, odour, cohesiveness, hardness, etc. Nowadays most of the diseases result from inadequate feeding and some of them may be related to insufficient fiber intake, it is reasonable to assume that an increased consumption of indigestible components would be important (Walter, Picolli da Silva, & Denardin, 2005). As a result consumers are in need of good-tasting, high fiber foods. From this point of view RS sources can be included in to diet, since they do not cause pronounced organoleptic alterations as do traditional fiber sources like bran.

Determination of the textural parameters after pasta cooking is of great importance from the point of product acceptability by the consumers. Generally, pasta is consumed within a short period after cooking. Good quality pasta is defined as having high degree of firmness and elasticity, which is mainly, termed as “al dente” (Antognelli, 1980; Pomeranz, 1987). Proper evaluation of pasta cooking quality requires consideration of a number of factors including elasticity, firmness, surface stickiness, cooking tolerance, water absorption, and loss of solids to cooking water. Taste panels can be used to estimate pasta cooking quality, but they are time consuming and impractical when sample size is limited or large numbers of samples are to be evaluated (Edwards, Izydorczyk, Dexter, & Biliaderis, 1993). Therefore rapid instrumental methods that consider a number of textural factors have been developed (Smewing, 1997). A very popular one is the texture profile analysis based on the recognition of texture as a multi parameter attribute. The test consists of compressing bite size pieces of food two times in a motion that simulates the action of jaw, and extracting from the resulting force time curve a number of textural parameters. These can be divided into the primary parameters of hardness, cohesiveness, springiness and adhesiveness and the secondary parameters of fracturability, chewiness and gumminess (Bourne, 1978; Szczesniak, 1963). In Durum wheat pasta, starch gelatinization and protein coagulation cause the major structural changes during cooking. Both transformations occur at approximately the same temperature and moisture level. There are several factors, which affect the characteristics of cooked pasta such as semolina protein quality and quantity, drying conditions and composition of cooking water (Cunin, Handschin, Walther, & Escher, 1995).

Little information is available on application and cooking characteristics of pasta enriched with insoluble starch fractions. In this work we focused on how addition of RS$_3$ alters the characteristics of cooked spaghetti. The cooking properties of spaghetti made from Durum wheat, enriched with bran and RS$_3$ were determined. Calorimetry and image analysis investigations were used to find out optimum cooking times and effect of RS and bran on gelatinization degree of starch. Several textural parameters such as hardness, adhesiveness, cohesiveness, chewiness and springiness were evaluated from TPA and compared with the results of a sensory panel.

2. Material and methods

2.1. Raw material

Resistant starch type III was supplied commercially. Durum wheat semolina was supplied from Beslen pasta factory (Gaziantep, Turkey).

2.2. Sample preparation

Control and spaghetti enriched with 10% (w/w) resistant starch were prepared in Beslen pasta factory (Gaziantep, Turkey). Bran spaghetti samples were supplied from a local supermarket.

All cooking tests were performed in duplicate. 10 g of spaghetti samples were broken into pieces of 10 cm and cooked in 250 ml boiling deionised water (Dexter, Matsuo, & Morgan, 1983). Boiling was kept at this level for the entire cooking period. Cooking properties of samples were measured in 2 min intervals starting from 6 min to 18 min. Samples were cooled by soaking in cold water for 10 s and excess water was removed by lightly patting between paper towels. The samples were immediately used for analytical and instrumental measurements. For DSC analysis samples were cooked starting from 2 min to 12 min and samples were taken every 2 min after they were cooled by soaking...
in cold water they were cut into 1 mm pieces and freeze-dried (Eyela Model FD-1, Tokyo Rikakikai Co., Tokyo, Japan) before evaluating the residual ungelatinized starch fraction, which was done after rehydrating the freeze-dried sample to a known moisture content (Riva, Fessas, & Schiraldi, 2000).

2.3. Analytical measurements

2.3.1. Moisture content

Moisture content of uncooked samples was determined by drying 2 g of sample for 2 h at 105 °C (Association of Official Analytical Chemists (AOAC), 1995).

2.3.2. Water absorption

Cooked samples were weighed soon after removing the excess water and dried in an oven at 105 °C for 2 h. Water absorption was expressed as percent water absorption.

2.3.3. Protein content

Protein content for uncooked spaghetti was determined as described by the standard Kjehdahl method (Malcolmson, Matsuo, & Balshaw, 1993) and expressed in percent dry basis.

2.4. Instrumental measurements

2.4.1. Image analysis

Degree of cooking was monitored by examining cross-sectioned images of cooked and drained spaghetti (Riva et al., 2000). Samples cooked for 6–18 min within 2 min intervals were cut into 1 mm thickness and replaced on glass slides, which were covered immediately with lamellas. All the samples were monitored under microscope (Olympus BX51, Olympus Co. Ltd., Japan) before evaluating the residual ungelatinized starch fraction, which was done after rehydrating the freeze-dried sample to a known moisture content (Riva, Fessas, & Schiraldi, 2000).

2.4.2. Thermal analysis

DSC measurements were done to semolina, uncooked spaghetti and freeze-dried cooked spaghetti after gently grinding with a mortar and paste to pass through a 0.25 mm mesh screen and packed into culture tubes. The moisture content of the samples were immediately determined after milling by an Infrared Dryer (Sartorius Thermo-Control YTC, Göttingen, Germany). Ground samples were weighed (10 mg) into DSC pans and moistened with distilled deionized water with a ratio of dry sample to water around 1:3.5. The DSC pans were sealed and let to reach equilibrium conditions in a refrigerator at 4 °C for overnight.

The measurements were carried out in a Perkin–Elmer DSC 6 equipped with a Pyris software (Perkin Elmer Inc., Wellesley, USA) calibrated with indium and empty pan as a reference. The samples were heated at a rate of 5 °C/min from 20 to 140 °C with nitrogen flushing (40 cm³/min). Each experiment was carried out in duplicate.

For each endotherm, onset (T_o), melting (T_m), and conclusion (T_c) temperatures were determined using the Pyris DSC software programme. The melting ranges (ΔT_c = T_c − T_o) were calculated. The heat flow signals were recorded in an ASCII format and analyzed with SigmaPlot for Windows (v 6.0, SPSS Inc. Chicago, Illinois, USA).

Degree of gelatinization (%) was determined as follows (Ndife, Şumnu, & Bayindirli, 1998):

\[
\text{Gelatinization degree (%)} = \left(1 - \frac{\Delta H_c}{\Delta H_s}\right) \times 100
\]

ΔH_c: gelatinization enthalpy at various cooking times (J/g db)
ΔH_s: gelatinization enthalpy of semolina (J/g db)

2.4.3. Texture profile analysis

The TA-XT2i Texture Analyzer (Stable Micro Systems Ltd., Godalming, Surrey, UK) fitted with a 25 kg load cell was used. Four spaghetti samples were placed adjacent to one another centrally under the compression platen of pasta firmness/stickiness rig. The test and post test speed were 1 mm/s. The test is a simulation of the action of jaw by compressing the bite size of food two times. The resulting force–time curve is used to extract number of textural parameters. These are primary parameters (hardness, cohesiveness, springness and adhesiveness) and secondary parameters (brittleness, chewiness, gumminess and resilience). The TPA test was performed in duplicate.

2.5. Sensory analysis

Spaghetti samples were cooked in distilled water to optimum cooking times. The sensory test panel consisted of 7 panellists (4 female and 3 male, 23–40 years old) selected from previously trained academic staff. Panellists received training to define texture terms for the spaghetti two weeks before test and they were asked to do a pre-panel one week before the real panel. The following textural parameters were evaluated: hardness, the resistance of cooked pasta to compression by the teeth, was measured by compressing the spaghetti strand against the palate with the tongue. Adhesiveness was evaluated by placing the spaghetti in the mouth, pressing it against the palate and determining the force required to remove it with the tongue. Chewiness was measured as the number of chews to masticate a known amount of sample at a constant rate of force application to reduce it to a consistency ready for swallowing. Cohesiveness was measured as the rate at which the spaghetti strands disintegrate under mechanical action. Springiness was measured as the degree to which the product returns to its original shape after partial compression.
(without failure) between the tongue and palate or teeth. Each of these five parameters was evaluated on a scale ranging from 0 to 9 (Szczesniak, Brandt, & Friedman, 1963).

3. Results and discussion

3.1. Degree of cooking by thermal and image analyses

Starch gelatinization and melting is an important phenomenon occurring in various food processing operations because it provides unique textural and structural characteristics for the products. The knowledge of the kinetics of starch gelatinization and melting is required for food process engineers to design and optimize processes such as extrusion and cooking of pasta (Spigno & De Faveri, 2004). Starch is the major component of semolina, and firmness in cooked spaghetti must, in part, be influenced by gelatinized starch properties (Dexter & Matsuo, 1979). The native starch granule is a partially crystalline polymer system which loses its crystallinity and molecular order during gelatinization. The gelatinization temperature is characteristic of the starch type and depends on the glass transition of the amorphous fraction of the starch (Eerlingen & Delcour, 1995).

Fig. 1 shows the changes in DSC gelatinization endotherms that decreased in magnitude with increasing cooking time. The onset and peak temperatures of gelatinization were found 58 and 64°C, respectively. Table 1 shows the mean values for DSC gelatinization of starch from semolina, uncooked and cooked spaghetti samples. The analysis of the peak temperatures did not make so much difference between the different spaghetti samples. However, the range for gelatinization temperatures made some difference. Uncooked spaghetti enriched with RS had the lowest gelatinization temperature range and enthalpy since it loses its crystallinity during processing (Yeo & Seib, 2000). When water migration increased, as cooking time proceeded, ΔH values decreased for all spaghetti samples which can be explained with the beginning of gelatinization starch granules becomes less thermostable and less energy is required to melt its structure (Biliaderis, 1990). Fig. 2 shows the gelatinisation (%) with respect to cooking time (min). Spaghetti with RS found to gelatinize at a faster rate than bran and control spaghetti. In fact, the lack of gelatinization endotherm meant the sample was completely gelatinized (Ndife et al., 1998; Riva et al., 2000) these results were not in agreement of the findings from image analysis. Since there are still some ungelatinized starch portions after 10 min of cooking, cooking was continued till the darkness in the images which refers to ungelatinized starch portions is lost.

![DSC thermograms of semolina and partially cooked control spaghetti](image-url)

### Table 1

Thermal characteristics of spaghetti samples: onset (T_o), peak (T_p), and completion (T_c) temperatures, gelatinization enthalpies (ΔH), and gelatinization ranges (ΔT_r = T_c - T_o)

<table>
<thead>
<tr>
<th>Spaghetti type</th>
<th>Cooking time (min)</th>
<th>T_o (°C)</th>
<th>T_p (°C)</th>
<th>T_c (°C)</th>
<th>ΔT_c (°C)</th>
<th>ΔH (J/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0</td>
<td>57.42 ± 0.04</td>
<td>63.00 ± 0.56</td>
<td>68.64 ± 0.78</td>
<td>11.22 ± 0.83</td>
<td>3.19 ± 0.08</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>57.85 ± 0.52</td>
<td>62.73 ± 0.34</td>
<td>68.42 ± 0.63</td>
<td>10.57 ± 0.11</td>
<td>2.93 ± 0.24</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>58.50 ± 0.17</td>
<td>62.46 ± 0.15</td>
<td>67.87 ± 0.25</td>
<td>9.37 ± 0.42</td>
<td>1.71 ± 0.32</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>58.91 ± 0.16</td>
<td>62.57 ± 0.75</td>
<td>68.16 ± 0.55</td>
<td>9.25 ± 0.72</td>
<td>1.47 ± 0.02</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>58.94 ± 0.42</td>
<td>63.23 ± 0.45</td>
<td>67.76 ± 0.15</td>
<td>8.82 ± 0.26</td>
<td>0.62 ± 0.01</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>62.12 ± 0.04</td>
<td>65.56 ± 0.17</td>
<td>67.97 ± 0.84</td>
<td>5.85 ± 0.83</td>
<td>0.47 ± 0.03</td>
</tr>
<tr>
<td>RS</td>
<td>0</td>
<td>57.79 ± 1.30</td>
<td>63.15 ± 0.37</td>
<td>68.36 ± 0.84</td>
<td>10.57 ± 1.14</td>
<td>2.17 ± 0.34</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>58.63 ± 1.58</td>
<td>63.54 ± 1.05</td>
<td>68.68 ± 1.11</td>
<td>10.05 ± 0.46</td>
<td>1.62 ± 0.02</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>58.53 ± 0.73</td>
<td>63.23 ± 0.01</td>
<td>68.41 ± 1.81</td>
<td>9.98 ± 1.55</td>
<td>1.28 ± 0.02</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>58.73 ± 0.61</td>
<td>63.29 ± 0.36</td>
<td>67.34 ± 1.58</td>
<td>9.61 ± 1.19</td>
<td>0.82 ± 0.02</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>60.05 ± 0.73</td>
<td>65.06 ± 0.16</td>
<td>68.39 ± 0.66</td>
<td>8.34 ± 0.06</td>
<td>0.25 ± 0.01</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>60.85 ± 0.71</td>
<td>65.36 ± 1.50</td>
<td>68.44 ± 0.70</td>
<td>7.59 ± 0.01</td>
<td>0.12 ± 0.01</td>
</tr>
<tr>
<td>Bran</td>
<td>0</td>
<td>58.06 ± 1.33</td>
<td>63.89 ± 0.01</td>
<td>69.19 ± 1.38</td>
<td>11.13 ± 2.71</td>
<td>3.45 ± 1.42</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>57.53 ± 0.08</td>
<td>63.37 ± 0.01</td>
<td>68.65 ± 0.77</td>
<td>11.12 ± 0.69</td>
<td>3.33 ± 0.11</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>59.19 ± 0.93</td>
<td>63.67 ± 0.29</td>
<td>67.67 ± 2.26</td>
<td>8.48 ± 2.18</td>
<td>1.24 ± 0.71</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>60.54 ± 1.14</td>
<td>64.48 ± 0.15</td>
<td>69.23 ± 2.24</td>
<td>8.69 ± 2.38</td>
<td>1.11 ± 0.16</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>59.67 ± 0.63</td>
<td>64.15 ± 0.25</td>
<td>68.16 ± 1.36</td>
<td>8.49 ± 1.98</td>
<td>0.62 ± 0.91</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>61.33 ± 0.09</td>
<td>65.31 ± 0.21</td>
<td>68.56 ± 2.21</td>
<td>7.23 ± 2.12</td>
<td>0.30 ± 0.04</td>
</tr>
</tbody>
</table>
Degree of cooking can be observed either by eye or image analysis. In this study it was determined by the disappearance of the black core in the centre of images (Fig. 3). Image analysis enabled to calculate uncooked and cooked areas much more easily and correctly. As cooking time proceeded both the cooked area and total area increased. Optimum cooking time was determined as the time when nearly 100% gelatinization was achieved. From the ratio of cooked area to total area, which is shown in Fig. 4, optimum cooking times were determined. From the image analysis the optimum cooking times were determined as 12.5, 13, 12 min for control, RS and bran spaghetti, respectively.

### 3.2. Water absorption and losses during cooking

Swelling of spaghetti strands occurs during cooking of spaghetti. Water uptake shows how well spaghetti responds to cooking. Table 2 represents the water absorption (%) of all spaghetti types. Water absorption of spaghetti enriched with RS was highest due to high amylose content of RS. It is known that amylose has higher water binding capacity than native starch (Zhiqiang, Xiao-su, & Yi, 1999). Increase in cooking time also caused an increase in water absorption since more water can diffuse and interact with both gluten and starch. During cooking dried gluten acts as a sponge for water, opens its structure and embeds the starch granules inside this network. Bran containing spaghetti absorbed less water than control and RS spaghetti till the overcooked region.

Cooking loss is the amount of dry matter lost into the cooking water of optimally cooked spaghetti. Cooking loss was highest in spaghetti enriched with bran and lowest for control spaghetti (Fig. 5). The increase in cooking loss with bran containing spaghetti may be due to weakening of protein network by the presence of bran.

### 3.3. Texture profile analysis

Textural parameters, especially firmness and adhesiveness are important for spaghetti cooking quality. The hard-
ness values of bran spaghetti were higher than the control and RS spaghetti (Table 4). However, it did not make so much difference between control and RS spaghetti. Differences in firmness values mainly arise from the differences in gluten fraction. Increasing the amount of gluten in spaghetti decreases the amount of residue in the cooking water and increases the force required to produce a given extension in cooked spaghetti (Matsuo & Irvine, 1970). The protein content of bran spaghetti was higher than the other two spaghetti types (Table 3).

Adhesiveness or stickiness is related with the amount of starch and starch gelatinization. In the early stages of cooking adhesiveness values were found to be higher and it decreased as cooking time proceeded (Table 4). Especially, when its in the optimum cooking time region which is roughly 12 min for each spaghetti type adhesiveness values were lowest. Water cannot diffuse into inner layers up to optimum cooking time and protein network does not develop as a result starch leaches into cooking water easily. During cooking, severe changes in the microstructure of pasta occurs. The uniformity of dry pasta starts to change by the diffusion of water from outside to the core. Closer to the surface of the spaghetti strand the changes are more drastic, starch granules are no longer intact as in the core and protein matrix starts to break down due to denaturation. Even the gluten matrix is still elastic enough in the centre (Voisey, Wasik, & Loughheed, 1978). In general adhesiveness values of bran containing spaghetti were higher than the other two types.

Cohesiveness can be a good indicator of how the sample holds together upon cooking. There was not so much difference between cohesiveness values of control and RS con-
taining spaghetti (Table 4). Since bran had a kind of diluting effect on gluten network, bran containing spaghetti had the lowest cohesiveness (Kordonowy & Youngs, 1985). This meant that it was more difficult for the bran containing spaghetti to hold the structure together as cooking time proceeded.

Chewiness which is related to the elastic strength of the protein matrix was highest for bran containing spaghetti. As cooking time proceeded chewiness of all spaghetti types decreased dramatically (Table 4) due to possible breakdown of gluten network and leaching of starch to cooking water.

Two way (cooking time, spaghetti type) interactions were examined by means of analysis of variance (Table 5). The cooking time-spaghetti type interactions was not significant for chewiness ($P > 0.05$). Interactions between other TPA parameters were found to be significant. LSD multiple range test was also carried out to determine the effect of cooking time and spaghetti type on TPA parameters (Table 6). The effect of cooking time and spaghetti type on hardness, adhesiveness, cohesiveness and chewiness during cooking were significant ($P < 0.05$).

### 3.4. Pearson correlation among sensory and instrumental textural properties

Instrumental measurement of cooked spaghetti texture can be a reliable and convenient alternative to the sensory panel. In fact sensory evaluation of spaghetti eating quality is a direct method for determining the quality of cooked spaghetti its quite laborious and expensive. Objective methods are quicker and give more accurate results but an objective method without any correlation to sensory judgement makes no sense. From this point of view Pearson correlation analysis was performed on control, RS and bran enriched cooked spaghetti samples to compare objective and subjective evaluations. The results of texture profile analysis correlated well with the sensorial judgement of hardness, adhesiveness and cohesiveness (Table 7). There was a strong correlation between instrumental chewiness-sensory hardness, and a strong negative correlation between instrumental cohesiveness sensory adhesiveness and hardness values. This sensorial finding was interesting since this was not something expected. The reason can be the presence of bran that causes an increase in both adhe-

### Table 5
Two-way ANOVA for cooked spaghetti samples

<table>
<thead>
<tr>
<th>TPA parameters</th>
<th>Source</th>
<th>Sum of squares</th>
<th>Degree of freedom</th>
<th>Mean square</th>
<th>F-ratio</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
<td>Cooking time</td>
<td>10948.10</td>
<td>6</td>
<td>1824.68</td>
<td>166.28</td>
<td>$P &lt; 0.05$</td>
</tr>
<tr>
<td></td>
<td>Spaghetti type</td>
<td>2051.96</td>
<td>2</td>
<td>1025.98</td>
<td>93.49</td>
<td>$P &lt; 0.05$</td>
</tr>
<tr>
<td></td>
<td>Interaction cooking time – spaghetti type</td>
<td>342.21</td>
<td>12</td>
<td>28.51</td>
<td>2.60</td>
<td>$P &lt; 0.05$</td>
</tr>
<tr>
<td>Adhesiveness</td>
<td>Cooking time</td>
<td>1.27</td>
<td>6</td>
<td>0.21</td>
<td>33.12</td>
<td>$P &lt; 0.05$</td>
</tr>
<tr>
<td></td>
<td>Spaghetti type</td>
<td>2.06</td>
<td>2</td>
<td>1.03</td>
<td>160.14</td>
<td>$P &lt; 0.05$</td>
</tr>
<tr>
<td></td>
<td>Interaction cooking time – spaghetti type</td>
<td>0.84</td>
<td>12</td>
<td>0.01</td>
<td>0.001</td>
<td>$P &lt; 0.05$</td>
</tr>
<tr>
<td>Cohesiveness</td>
<td>Cooking time</td>
<td>0.08</td>
<td>6</td>
<td>0.01</td>
<td>31.05</td>
<td>$P &lt; 0.05$</td>
</tr>
<tr>
<td></td>
<td>Spaghetti type</td>
<td>0.08</td>
<td>2</td>
<td>0.04</td>
<td>93.99</td>
<td>$P &lt; 0.05$</td>
</tr>
<tr>
<td></td>
<td>Interaction cooking time – spaghetti type</td>
<td>0.01</td>
<td>12</td>
<td>0.001</td>
<td>2.36</td>
<td>$P &lt; 0.05$</td>
</tr>
<tr>
<td>Chewiness</td>
<td>Cooking time</td>
<td>3365.44</td>
<td>6</td>
<td>560.91</td>
<td>70.11</td>
<td>$P &lt; 0.05$</td>
</tr>
<tr>
<td></td>
<td>Spaghetti type</td>
<td>526.64</td>
<td>2</td>
<td>163.32</td>
<td>20.41</td>
<td>$P &lt; 0.05$</td>
</tr>
<tr>
<td></td>
<td>Interaction cooking time – spaghetti type</td>
<td>59.96</td>
<td>12</td>
<td>4.99</td>
<td>0.62</td>
<td>N.S.</td>
</tr>
</tbody>
</table>

### Table 6
LSD multiple range analysis of TPA parameters for cooked spaghetti samples

<table>
<thead>
<tr>
<th>Effect</th>
<th>Spaghetti type</th>
<th>LS Mean ± standard error*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Hardness</td>
</tr>
<tr>
<td>Control</td>
<td>40.23 ± 0.88a</td>
<td>0.43 ± 0.02a</td>
</tr>
<tr>
<td>RS</td>
<td>39.85 ± 0.88a</td>
<td>0.53 ± 0.02b</td>
</tr>
<tr>
<td>Bran</td>
<td>54.86 ± 0.88b</td>
<td>0.94 ± 0.02c</td>
</tr>
</tbody>
</table>

Cooking time (min)

<table>
<thead>
<tr>
<th></th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>16</th>
<th>18</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>75.97 ± 1.53a</td>
<td>59.23 ± 1.33b</td>
<td>47.98 ± 1.35c</td>
<td>38.89 ± 1.35d</td>
<td>34.34 ± 1.35e</td>
<td>30.64 ± 1.35ef</td>
<td>27.97 ± 1.35f</td>
</tr>
</tbody>
</table>

* Means within a column followed by different levels are significantly different ($P < 0.05$).
siveness and hardness. The increase in adhesiveness is due to bran particles preventing formation of strong gluten network. The other factors assessed in the sensory results and TPA parameters did not give significant correlations.

4. Conclusions

Resistant starch, being a part of dietary fibre is a good alternative to fibres like bran. Its possible to find bran containing spaghetti on the shelves, which is a good source of dietary fibre. But consumers still do not like to include this product into their diet due to undesirable flavour, colour and texture. Resistant starch is odourless, and does not alter the organoleptic properties of the original product. Thermal and textural parameters besides some basic quality tests like cooking loss and water absorption gave us information about how addition of RS affected the structure of spaghetti. DSC gelatinisation endotherms found to decrease in magnitude with increasing cooking time. Uncooked spaghetti enriched with RS had the lowest gelatinisation temperature range and enthalpy since it loses its crystallinity during processing. Also while cooking, RS spaghetti found to gelatinise at a faster rate than bran and control spaghetti.

Textural properties, such as firmness and adhesiveness are one of the most important parameters for cooking quality. Spaghetti enriched with RS was found to be better than bran containing spaghetti. It was less sticky and the firmness values were close to control spaghetti. The effects of cooking time and spaghetti type on textural parameters were found to be significant. Spaghetti enriched with RS had lower cooking losses as compared to bran containing spaghetti. A sensorial panel was performed to find out the correlation between instrumental and sensory hardness, adhesiveness, chewiness, and springiness. Instrumental hardness, adhesiveness and cohesiveness correlated well with sensorial evaluations. The main reason why sensory and instrumental chewiness and springiness correlate so poorly was that they were difficult to quantify by the panellists.

Table 7

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Shard.</td>
<td>1</td>
<td>0.981</td>
<td>0.696</td>
<td>-1</td>
<td>0.656</td>
<td>0.996</td>
<td>0.998</td>
<td>0.613</td>
<td>0.498</td>
</tr>
<tr>
<td>Sadh.</td>
<td>0.981</td>
<td>1</td>
<td>0.823</td>
<td>-0.698</td>
<td>1</td>
<td>1</td>
<td>0.998</td>
<td>-0.613</td>
<td>-0.756</td>
</tr>
<tr>
<td>Schew.</td>
<td>0.696</td>
<td>0.823</td>
<td>1</td>
<td>0.996</td>
<td>0.996</td>
<td>0.996</td>
<td>0.996</td>
<td>0.975</td>
<td>0.997</td>
</tr>
<tr>
<td>Scohes.</td>
<td>-1</td>
<td>-0.698</td>
<td>-0.698</td>
<td>0.656</td>
<td>0.656</td>
<td>0.568</td>
<td>0.997</td>
<td>0.973</td>
<td>0.973</td>
</tr>
<tr>
<td>Spr.</td>
<td>-0.613</td>
<td>-0.756</td>
<td>-0.994</td>
<td>0.615</td>
<td>-0.191</td>
<td>-0.568</td>
<td>-0.684</td>
<td>-0.496</td>
<td>0.677</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level.
* Correlation is significant at the 0.05 level.

Acknowledgement

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References


