Chapter 6

Development of whole-grain noodle from nixtamal
6.1. Summary

Nixtamalization is a well-known pre-treatment technique in the tortilla industry for its desirable modification in maize grain’s physico-chemical as well as nutritional attributes. In the present study two types of nixtamalization processes (traditional and ecological) were employed for the development of whole-grain-maize-based noodles using Dent and Flint maize genotypes. The effect of nixtamalization was compared with the noodles prepared from raw maize grain and the cooking and textural properties of the maize noodles were compared with that of wheat noodle. Cooked weight, percent rehydration and solid loss values of maize noodles ranged from 73 ± 0.7 to 95.1 ± 0.5, 192 ± 2.8 to 280 ± 2.1% and 6 ± 0.3 to 12.8 ± 0.5%. The texture analysis data revealed that nixtamalization resulted in desirable textural quality of the noodles. However, ecological nixtamalization had resulted in better cooking and textural qualities in noodles than did traditional nixtamalization. Visco-amylography results showed that Dent maize had undergone excessive cross-linking during nixtamalization affecting the pre-gelatinization process unlike Flint maize. Traditional nixtamalization negatively affected the phenolic compounds and their antioxidant properties unlike ecological process which retains the pericarp and maintains the nejayote (wastewater) within the acidic-neutral range. Sensory analysis showed that noodle from ecological nixtamalization of Flint maize was most acceptable among the maize noodles prepared.

6.2. Introduction:

In recent years Asian noodles have gained popularity worldwide. Noodles are one of the many convenience foods prepared through extrusion process and have been considered to symbolize long life and good luck in Asian culture (Sowbhagya and Ali, 2001). Wheat is the principal cereal grain which is extensively used for the production of noodles. However, the grain is not considered safe for the people
suffering from celiac disease because of its major constituent protein-gluten. Therefore, the celiacs who are allergic to gluten ought to obtain their daily nutrients from non-glutinous cereal sources (Torbica et al., 2010). On the contrary, the absence of ‘gluten’ from the cereals makes it challenging to develop noodle and alike products because of the said protein’s capacity to hydrate, swell and form an elastic dough. Dough prepared from non-glutinous cereals lacks in cohesiveness and elasticity which are essential for the formation of noodle strand. In the recent past, a great deal of effort has been made to alternatively develop rice-based products comparable in quality to wheat-based foods. However, the primary research was focussed on baked products such as bread. Therefore, the need arises to pay more extensive attention to the products like noodle which is the second most consumed foods in the world, next to the bread (Jayasena et al., 2008).

In previous studies it was shown that prolamin polymers are formed in maize on cooking (Ezeogu et al., 2005, 2008). Zein, a major prolamin protein of maize, polymerizes as a result of disulphide bonding during cooking (Emmambux and Taylor, 2009). More recently, Guzman et al. (2010, 2011) showed that nixtamalization (lime cooking of maize) polymerizes maize protein through calcium bridges via calcium-zein and zein-calcium-zein interactions, in addition to disulphide bonding. Calcium bridges are difficult to disrupt and causes thermo-resistance of the protein. The combined effects of lime on starch cross-linking, the formation of zein polymers and calcium-zein interactions during cooking, yielded a stronger and more elastic gel structure. Hence, it was hypothesized that the use of nixtamalization in the processing of maize in order to develop whole-grain-gluten-free noodle may have a clear implication on the product’s desirable quality.

However, the phytochemical profile of foods as affected by processing becomes an important issue. Phenolic compounds are a
significant group of phytochemicals in maize. They possess bioactive properties such as antioxidant activity and offer potential health benefits as discussed in previous chapters. Processing of cereals and legumes may enhance or reduce the levels of phenolic compounds in foods and their bioactive properties. Investigations on nixtamalization with respect to phytochemical profile revealed the leaching of antioxidative phenolics in the nejayote (cooking liquor). However, it was also documented that nixtamalization releases bound phenolics associated to cell walls due to alkaline hydrolysis (De la Parra et al., 2007; Del Pozo-Insfran et al., 2007; Gonzalez et al., 2004). In order to overcome the leaching of phenolics through the above traditional nixtamalization, Carrera et al. (2012) used ecological nixtamalization [use of calcium salts such as calcium chloride-CaCl₂, calcium sulphate-CaSO₄, calcium carbonate-CaCO₃ and calcium acetate-Ca(CH₃COO)₂ instead of calcium hydroxide-Ca(OH)₂] for tortilla production and found lesser solid loss in nejayote. In a similar study Rodriguez Mendez et al. (2013) found that ecological nixtamalization maintains slightly acidic or neutral medium which is desirable for phenolics and retains a higher proportion of the pericarp.

Hence, in the present study whole grain maize noodle was developed from nixtamalized (traditional and ecological) Dent and Flint maize with minimalized loss of bioactive phenolic compounds.

6.3. Materials and methods:

6.3.1. Materials:

The Folin Ciocalteu reagent, phenolic acid standards, trolox, DPPH, catechin and ferrozine were purchased from Sigma-Aldrich (St. Louis, MO). Hydrogen peroxide was used from fresh bottle and was purchased from Merck Specialities Private Limited, Mumbai, India. Sep-pak C₁₈ cartridges were purchased from Waters Corporation, Milford, Massachusetts, USA. Solvents used for HPLC analyses were of HPLC grade. Methanol, sodium carbonate, potassium ferricyanide,
TCA, ferric chloride, sodium nitrite, aluminum chloride, TBA, ferrous chloride, potassium persulphate all other solvents and acids were of analytical grade, whereas triple distilled water was used wherever necessary.

6.3.2. Traditional nixtamalization:
Traditional nixtamalization flour was produced as per the method of Carrera et al. (2012) with some modifications. One kg of maize was cooked in 2 L of water and 1% (w/w) calcium hydroxide solution for 23 min. The cooked grains were steeped for 16 h at room temperature before the cooking liquor or nejayote was decanted and collected. The cooked maize called nixtamal was then rinsed with purified water in order to eliminate the excess calcium hydroxide and dried in a hot air oven at 50-55 °C to a moisture level of 10-12%.

6.3.3. Ecological nixtamalization:
In the ecological nixtamalization process calcium hydroxide was replaced with calcium carbonate. One kg of maize was cooked in 2 L of water and 1% (w/w) calcium carbonate solution for 23 min. The cooked grains were steeped for 16 h at room temperature before the nejayote was decanted and collected. The nixtamal was rinsed with purified water and then dried in a hot air oven at 50-55 °C to a moisture level of 10-12% (Carrera et al., 2012).

6.3.4. Flour preparation:
The resulting nixtamal obtained from the above traditional and ecological nixtamalization processes was ground to flour in a hammer mill and sifted through 150 µm (100 mesh) screen. The flour was packed into polythene bags and stored in a cold room at 4 °C until use. Whole grain flour from Dent and Flint maize was also milled through the above method to use them as control flour. There were totally three types of flours prepared for noodle development viz. CF (control flour), TF (traditional-nixtamalized flour) and EF (ecological-nixtamalized flour) from each of Dent and Flint maize.
6.3.5. Noodle preparation:

Flour from control and nixtamal was used to prepare noodles. Flour and tapioca starch were mixed in a proportion of 98:2 and then added with 0.3% (w/w) of gum arabic. Common salt (2%, w/w) and sodium bicarbonate (0.2%, w/w) were separately dissolved in 300 mL of purified water and this solution was added to the flour to make a stiff dough (~30% moisture) by kneading for a while. The dough so made was extruded through a low-pressure, single-screw extruder (La Prestigiosa 4500, Italy) in the form of noodle strands (Fig. 6.1). Soon after the extrusion the noodle strands were steam-cooked (open atmosphere) in an autoclave for 45 min. The steam-cooked noodle strands were removed from the autoclave and immediately placed under the stream of cold water so as to allow retrogradation of starch which imparts hardness to the strands. The noodles were dried in a hot air oven at 50-55 °C for about 2 h and then packed in zip-locked pouches. There were totally three types of noodles prepared from three types of flours each of Dent and Flint maize. These are CN (control noodle), TN (traditional-nixtamalized noodle) and EN (ecological-nixtamalized noodle).

Fig. 6.1: Whole-grain maize noodle being extruded from low-pressure, single-screw extruder.
6.3.6. Cooking quality of the noodles:

Cooking quality of the maize noodles was analyzed according to AACC method (66–50). Noodle strands were cut to approximately 5 cm by length. The strands (25 g) were cooked in 250 mL of boiling water. At an interval of every 30 s a noodle strand was examined by pressing between two glass slides to check the disappearance of the white core portion which indicates the noodles are cooked completely. The resultant gruel was decanted and collected for the determination of the solid loss. Cooked noodles were weighed to determine percent rehydration.

\[
\text{% Solid loss} = \frac{\text{Weight of dried residue}}{\text{Weight of uncooked noodle}} \times 100
\]

\[
\text{% Rehydration} = \frac{\text{Weight of cooked noodle} - \text{Weight of uncooked noodle}}{\text{Weight of uncooked noodle}} \times 100
\]

6.3.7. Instrumental texture analysis:

The strength of the uncooked dry noodles was determined by measuring the breaking strength using a texture measuring instrument (TA-HD Plus, Stable Micro Systems, Surrey, UK) with a 3-point bending rig having a round end blade. The breaking strength of the uncooked noodle samples was determined at a test speed of 1 mm/s. A 5 Newton load cell was used, and the distance travelled by the blade was up to 15 mm to ensure complete failure during testing. At least five replicates for each sample were examined. A wheat noodle sample procured from local market was also analyzed alongside to compare the results.

The texture of the cooked noodles was assessed in terms of hardness (maximum force registered during the compression), compression energy (positive area during the compression up to 75% strain) and firmness (initial slope of the compression curve). The above
mentioned texture measuring instrument fitted with a cylindrical flat probe of 35 mm diameter was used at a pretest speed of 2 mm/s, test speed of 1 mm/s and posttest speed of 10 mm/s. At least five replicates for each sample were examined. A wheat noodle sample procured from local market was also analyzed alongside to compare the results.

6.3.8. Viscoamylography analysis:

The gelatinization temperature and viscosity of the control, nixtamalized flour and noodle flour were measured in a Micro Visco-amylograph (Model No. 803202, Brabender, Duisburg, Germany) as per the method described by Itagi and Singh (2010). The control and nixtamalized flours (traditional and ecological) which were previously ground to flour in a hammer mill and sifted through 150 µm screen mesh (as described in section 6.2.4) were directly used for the analysis, whereas the noodles prepared from those flours were again ground to flour and sifted through 150 µm screen mesh for the analysis. The flour samples were converted to 13% slurry. The slurry was then heated from 30 to 92 °C at the rate of 7 °C/min and held at 92 °C for 5 min followed by cooling to 50 °C with 1 min holding. The pasting curves obtained were compared and the pasting parameters viz. paste viscosity or PV (maximum viscosity during heating phase), hot paste viscosity or HPV (minimum viscosity at 92 °C), CPV (final viscosity at 50 °C), break down or BD (PV-HPV) and total set back or SBt (CPV-HPV) were recorded. All the viscosity parameters were expressed as BU (Brabender unit).

6.3.9. Instrumental colour measurement:

The colour of uncooked noodles was measured with Labscan-XE (Reston, USA) equipped with D-65 illuminant with 2° view angle and slit width of 2 mm. The noodle samples were taken in a quartz container and placed on the slit opening to measure the surface colour. All the samples were subjected to three measurements and the
average value was reported. The colour parameters in terms of L* a* b* values were recorded, where L* indicates lightness/darkness dimension, positive and negative a* value suggests redness and greenness, respectively whereas b* depicts yellowness for positive and blueness for negative values.

6.3.10. **Proximate composition of noodles:**

Moisture, protein, fat and ash contents were determined as per AACC approved methods of analysis. Carbohydrate was determined by difference method.

6.3.11. **Extraction of free and bound phenolic constituents:**

Extraction methods of free and bound phenolic constituents standardized in chapter 3 (section 3.4.4 and 3.4.5), was employed in the present study.

6.3.12. **Determination of total phenolic and total flavonoid content:**

The total phenolic content was determined using the method of Singleton *et al.* (1999) as described in chapter 3 (section 3.4.6). FA was used as standard, and the results were expressed as μmoles of FAE/g of sample on db.

Total flavonoid content was determined by the aluminum chloride method with some modifications as described in chapter 3 (section 3.4.7). Catechin served as standard and the results were expressed in μmoles of CE/g of sample (db).

6.3.13. **Separation and fractionation of phenolic acids and flavonoids:**

Phenolic acids were separated by reverse phase HPLC (Shimadzu LC-8A, Shimadzu Corporation, Kyoto, Japan) HPLC fitted with C18 column (25 cm × 4 mm, 5 μm, Kromasil, India) and diode array detector. The detailed procedure is discussed in chapter 4 (section
4.2.6). Since flavonoid content could not be traced through spectrophotometric analysis (as discussed in section 6.3.6), separation of flavonoid compounds was not performed through HPLC method.

**6.3.14. Antioxidant capacities of nixtamalized flours, noodles and cooked noodles:**

Various *in vitro* antioxidant capacities *viz.* DDPH and ABTS free radical scavenging capacity, HPSC, FRAP, MCC and ILPC were determined as per the methods described in chapter 5.

**6.3.15. Sensory analysis of noodles:**

Developed noodles were evaluated for their sensory attributes and acceptance. Selected number of semi-trained panelists (Male and Female; 15 Nos.) had participated in the analysis. Preliminarily, important sensory attributes were suggested by the panelists’ and then the products were evaluated based on the suggested profile.

**6.4. Results and discussion:**

**6.4.1. Cooking quality of the noodles:**

The parameters related to cooking quality *viz.* cooked weight, percent rehydration and solid loss of noodles significantly (*p*<0.05) varied on nixtamalization (Table 6.1). The commercial wheat noodle cooked for a longer time (10.4 ± 0.1 min) compared to all the maize noodles. Cooked weight, percent rehydration and solid loss values of maize noodles ranged from 73 ± 0.7 to 95.1 ± 0.5, 192 ± 2.8 to 280 ± 2.1% and 6 ± 0.3 to 12.8 ± 0.5%.

The cooking time of wheat noodle is usually longer which ranges from 11 to 14.5 min (Ahmed *et al.*, 2015; Ritthiruangdej *et al.*, 2011). Rice noodles, on the other hand, cooks within 5 to 9 min (Fari *et al.*, 2011; Hormdok and Noomhorm, 2007). However, our maize noodles had even lesser cooking time of 3 to 5.5 min. The differences in gelatinization temperature of respective starches of different cereals
are responsible for the difference in cooking time of noodles. The smaller starch granules of non-glutinous cereals hydrate quickly than wheat causing decrease in cooking time (Ahmed et al., 2015).

The significantly higher (p<0.05) cooked weight of maize noodles than that of wheat noodle is due to relatively higher swelling power of starch granules of maize than wheat. Perhaps, gluten lowers the water imbibition of starch, which decreases the cooked weight.

Percent rehydration shows the ratio of weight of cooked noodles to the weight of uncooked noodles and may affect the eating quality of noodles (Fari et al., 2011). The rehydration of commercial wheat noodle was found to be 173.5 ± 2.1%, which is significantly lower than all the maize noodles (p<0.05). However, rice noodles have much higher rehydration of 146 to 290% (Qazi et al., 2014; Hormdok and Noomhorm, 2007) which falls in the range of our maize noodles. The percent rehydration has a great impact on the cooking qualities and texture of noodles. The instrumental texture profile (as discussed in section 6.3.2) shows that noodles with lower percent rehydration have better textural qualities.

High rehydration results in soft and sticky noodles and imparts higher solid loss during cooking. The solid loss is the amount of solid lost in the cooking water due to the high solubility of starch. It shows the ability of noodles to resist structural breakdown during cooking (Hatcher, 2001). Our observation on percent rehydration was substantiated with the results of percent solid loss of noodle samples. EN of Flint maize was found to have least solid loss (6 ± 0.3%), whereas CNs of both maize genotypes had solid loss higher than 8% which is above the acceptable limit (Bureau of Indian Standards). Since raw whole grain was used for CNs, the presence of fibrous pericarp and germ increased in cooking loss due to disruption of the protein-starch matrix and the uneven distribution of water within the system (Bharath Kumar and Prabhasankar, 2015a). Hence,
nixtamalization was proven to be useful and can be used as pre-treatment of maize to develop whole-grain maize based products.

**Table 6.1:** Cooking quality of the noodles

<table>
<thead>
<tr>
<th>Noodle sample</th>
<th>Cooking time (min)</th>
<th>Cooked weight (g)</th>
<th>Rehydration (%)</th>
<th>Solid loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dent maize CN</td>
<td>3.3±0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>95.1±0.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>280.5±2.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.8±0.5&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Dent maize TN</td>
<td>4.4±0.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>94.1±0.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>276.5±2.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.5±0.5&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Dent maize EN</td>
<td>4.4±0.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>76.9±0.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>207.5±3.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7.4±0.3&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Flint maize CN</td>
<td>3.1±0.08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>82.4±0.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>229.5±2.1&lt;sup&gt;d&lt;/sup&gt;</td>
<td>10.2±0.5&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Flint maize TN</td>
<td>5.3±0.04&lt;sup&gt;c&lt;/sup&gt;</td>
<td>76.5±0.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>206±1.4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7.8±0.2&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Flint maize EN</td>
<td>5.4±0.07&lt;sup&gt;c&lt;/sup&gt;</td>
<td>73±0.7&lt;sup&gt;d&lt;/sup&gt;</td>
<td>192±2.8&lt;sup&gt;e&lt;/sup&gt;</td>
<td>6.0±0.3&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Wheat</td>
<td>10.4±0.1&lt;sup&gt;d&lt;/sup&gt;</td>
<td>68.4±0.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>173.5±2.1&lt;sup&gt;f&lt;/sup&gt;</td>
<td>4.7±0.4&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Values are mean ± SD of two independent analyses (n=2). Values with different superscript within a column are significantly different (p<0.05). CN-control noodle, TN-traditional-nixtamalized noodle, EN-ecological-nixtamalized noodle.

**6.4.2. Instrumental texture analysis:**

Texture and mouthfeel of cooked noodles is the most critical characteristic that determines consumer acceptance of the product. Results of the instrumental texture analysis of uncooked and cooked noodles are given in Table 6.2. The breaking strength is the stress required to break across a noodle strand (Oh *et al.*, 1983). High breaking strength is desirable to minimize the breakage during handling and transportation. Uncooked wheat noodle sample had the highest breaking strength of 1.5 ± 0.05 Newton (p<0.05) followed by EN of Flint maize (1.4 ± 0.02 Newton). CN and TN of Dent maize exhibited the lowest breaking strength (0.94 ± 0.05 and 0.86 ± 0.02 Newton, respectively).

Similar to the above result of uncooked noodles, cooked wheat noodle sample exhibited significantly higher peak force (23 ± 0.9 Newton), compression energy (13.2 ± 0.3 mJ) and firmness (5.2 ± 0.2 Newton/mm) than all other maize noodle samples (p<0.05).
Among the maize noodles EN of Flint maize had higher peak force value (21 ± 0.3 Newton) and compression energy (11.5 ± 0.3 mJ) followed by TN (19 ± 0.1 Newton and 9.2 ± 0.3 mJ, respectively) and CN (14.1 ± 0.7 Newton and 7.2 ± 0.2 mJ, respectively) of Flint maize reflecting that EN of Flint maize was significantly harder than all other maize noodles however, softer than wheat noodle (p<0.05). Firmness is another important textural parameter used to identify the quality attributes of a product. It depicts the resistance by the product to the applied external force. Among maize noodle samples EN of Flint maize had the highest firmness (4.5 ± 0.2 Newton/mm) after wheat noodle (p<0.05). The decrease in firmness in maize noodles is due to the use of whole maize grain with high fiber content. Fiber disrupts the protein-starch matrix within the product’s microstructure (Bharath Kumar and Prabhasankar, 2015b).

The texture analysis data revealed that nixtamalization resulted in desirable textural quality of the products unlike in the control products despite using indifferent methodology for noodle preparation. This may be attributed to the fact that the combined effects of nixtamalization process on starch cross-linking, the formation of zein polymers and calcium-zein interactions (Guzman et al., 2010, 2011). However, between the two types of nixtamalization processes, ecological nixtamalization was found to be better than traditional nixtamalization in terms of enhancing the textural quality of the products. All the textural parameters depicted that Flint maize has a better suitability to be translated into noodle and similar products than Dent maize due the properties of starch and the higher content of amylose present in Flint maize. Yoenyongbuddhagal and Noomhorm (2002), demonstrated that rice cultivars with high amylose content have higher suitability for the preparation of noodle. It is noteworthy that the maize noodles with higher solid loss during cooking, exhibited inferior textural quality.
Table 6.2: Instrumental texture analysis of the noodles

<table>
<thead>
<tr>
<th>Noodle sample</th>
<th>Breaking strength (Newton)</th>
<th>Peak force (Newton)</th>
<th>Compression energy (mJ)</th>
<th>Firmness (Newton/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dent maize</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CN</td>
<td>0.94±0.05d</td>
<td>8.9±0.4a</td>
<td>4.1±0.09a</td>
<td>1±0.05a</td>
</tr>
<tr>
<td>TN</td>
<td>0.86±0.02d</td>
<td>13.4±0.7b</td>
<td>6.3±0.2b</td>
<td>1.1±0.1a</td>
</tr>
<tr>
<td>EN</td>
<td>1.3±0.09b</td>
<td>12.2±0.2c</td>
<td>7.3±0.3c</td>
<td>3.1±0.1c</td>
</tr>
<tr>
<td>Flint maize</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CN</td>
<td>1.1±0.1c</td>
<td>14.1±0.7b</td>
<td>7.2±0.2c</td>
<td>2±0.1b</td>
</tr>
<tr>
<td>TN</td>
<td>1.3±0.03b</td>
<td>19±0.1d</td>
<td>9.2±0.3d</td>
<td>3.2±0.2c</td>
</tr>
<tr>
<td>EN</td>
<td>1.4±0.02b</td>
<td>21±0.3e</td>
<td>11.5±0.3e</td>
<td>4.5±0.2d</td>
</tr>
<tr>
<td>Wheat</td>
<td>1.5±0.05a</td>
<td>23±0.9f</td>
<td>13.2±0.3f</td>
<td>5.2±0.2e</td>
</tr>
</tbody>
</table>

Values are mean ± SD of five independent analyses (n=5). Values with different superscript within a column are significantly different (p<0.05). CN=control noodle, TN=traditional-nixtamalized noodle, EN=ecological-nixtamalized noodle.

6.4.3. Visco-amylography analysis:

The pasting properties obtained from visco-amylography is a measure of the viscosity of cereal suspension during the heating cycle, which reflects the molecular events occurring in starch granules. Therefore, the integrity of starch granule and hydration properties resulting from the starch native properties, or from the inter- or intra-molecular interactions during hydrothermal treatment can easily be investigated. The results of various parameters measured by Brabender Visco-amylograph are shown in Table 6.3 and Fig. 6.2. The slurry of CF of Dent maize at 13% concentration on cooking had gelatinization temperature of 68.8 °C which decreased on nixtamalization, whereas for Flint maize nixtamalized flours showed high gelatinization temperature. It is well known that composition of maize kernels, and the starch undergoes many structural changes including partial gelatinization, melting, pasting, retrogradation (Shandhu and Singh, 2007; Rojas-Molina et al., 2007) and starch cross-linking (Mondragón et al., 2004, 2006). Generally partially gelatinized starch (as is supposed to occur during nixtamalization) requires higher energy for
undergoing further gelatinization. However, higher degree of cross linking reduces the proportion of starch granules that were capable of gelatinization by heat, this in turn, decreases the energy required for starch gelatinization even though a higher temperature is normally required for gelatinization. The granules of highly cross linked starch remain small and intact during cooking of the slurry and thus the viscosity remains low throughout the heating cycle as can be seen from the sudden drop in PV from CF to EF and TF of Dent maize. The PV of CF of Dent maize increased rapidly to 406 ± 11 BU and then showed lowered viscosity (327 ± 4.6 for EF and 244 ± 2.4 for TF) after nixtamalization. This phenomenon indicates that Dent maize undergoes higher degree of cross linking during nixtamalization than Flint maize which induces structural changes in starch through the formation of calcium bridges (Rodriguez et al., 1996). Visco-amylography results of Flint maize showed that it might have undergone low cross linking which did not affect the pre-gelatinization process as the gelatinization temperature increased after nixtamalization and there was no sudden drop in viscosity post nixtamalization. Pre-gelatinization is a desired phenomenon which is essential to develop extruded products like noodles from a non-glutinous cereal. In Flint maize the PV decreased on nixtamalization and further on noodle preparation which is caused by the excessive processing involved during nixtamalization and noodle preparation. The drastic drop in PV and loss of BD were observed in noodle flours of both the genotypes indicating restricted swelling of starch granules due to processing (Dutta and Mahanta, 2014; Mir and Bosco, 2013). The restricted swelling and amylase leaching in noodle flour could have decreased peak viscosity. Reduced amylase leaching after processing is an anticipated consequence because the processing involved in noodle preparation could cause additional amylase–amylase and amylase–amylopectin interactions within the starch granule reducing the leaching ability of amylase and it’s breaking down (Gunaratne and Hoover, 2002).
### Table 6.3: Visco-amylography analysis of nixtamalized flours and noodles

<table>
<thead>
<tr>
<th>Sample</th>
<th>Gelatinization Temp. (°C)</th>
<th>Peak viscosity (BU)</th>
<th>Hot paste viscosity (BU)</th>
<th>Cold paste viscosity (BU)</th>
<th>Break down (BU)</th>
<th>Total Set back (BU)</th>
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<tr>
<td></td>
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<tr>
<td>Dent Maize</td>
<td></td>
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<tr>
<td>CF</td>
<td>68.8±0.52&lt;sup&gt;a&lt;/sup&gt;</td>
<td>406±11&lt;sup&gt;a&lt;/sup&gt;</td>
<td>391±10.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>763±20.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15</td>
<td>372</td>
</tr>
<tr>
<td>TF</td>
<td>67.3±0.34&lt;sup&gt;b&lt;/sup&gt;</td>
<td>244±2.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>155±2.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>393±13.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>89</td>
<td>238</td>
</tr>
<tr>
<td>EF</td>
<td>65.4±0.42&lt;sup&gt;c&lt;/sup&gt;</td>
<td>327±4.6&lt;sup&gt;c&lt;/sup&gt;</td>
<td>327±3.4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>623±15.4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0</td>
<td>296</td>
</tr>
<tr>
<td>CN</td>
<td>84.1±1.2&lt;sup&gt;d&lt;/sup&gt;</td>
<td>153±2.1&lt;sup&gt;d&lt;/sup&gt;</td>
<td>152±2.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>217±3.5&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1</td>
<td>65</td>
</tr>
<tr>
<td>TN</td>
<td>61.7±0.57&lt;sup&gt;e&lt;/sup&gt;</td>
<td>37±1.4&lt;sup&gt;e&lt;/sup&gt;</td>
<td>37±1.1&lt;sup&gt;d&lt;/sup&gt;</td>
<td>55±1.6&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>EN</td>
<td>72.8±0.82&lt;sup&gt;f&lt;/sup&gt;</td>
<td>85±1.2&lt;sup&gt;f&lt;/sup&gt;</td>
<td>85±1.6&lt;sup&gt;e&lt;/sup&gt;</td>
<td>119±3.1&lt;sup&gt;f&lt;/sup&gt;</td>
<td>0</td>
<td>34</td>
</tr>
<tr>
<td>Flint Maize</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CF</td>
<td>66.4±0.46&lt;sup&gt;c&lt;/sup&gt;</td>
<td>297±5.2&lt;sup&gt;g&lt;/sup&gt;</td>
<td>296±6.4&lt;sup&gt;f&lt;/sup&gt;</td>
<td>532±12.8&lt;sup&gt;g&lt;/sup&gt;</td>
<td>1</td>
<td>236</td>
</tr>
<tr>
<td>TF</td>
<td>68.7±0.62&lt;sup&gt;a&lt;/sup&gt;</td>
<td>261±4.8&lt;sup&gt;h&lt;/sup&gt;</td>
<td>240±5.3&lt;sup&gt;g&lt;/sup&gt;</td>
<td>508±10.4&lt;sup&gt;g&lt;/sup&gt;</td>
<td>21</td>
<td>268</td>
</tr>
<tr>
<td>EF</td>
<td>70.5±0.67&lt;sup&gt;g&lt;/sup&gt;</td>
<td>290±5.8&lt;sup&gt;g&lt;/sup&gt;</td>
<td>288±5.4&lt;sup&gt;f&lt;/sup&gt;</td>
<td>525±9.7&lt;sup&gt;g&lt;/sup&gt;</td>
<td>2</td>
<td>237</td>
</tr>
<tr>
<td>CN</td>
<td>70.8±0.72&lt;sup&gt;g&lt;/sup&gt;</td>
<td>65±1.4&lt;sup&gt;i&lt;/sup&gt;</td>
<td>65±1.3&lt;sup&gt;h&lt;/sup&gt;</td>
<td>98±2.1&lt;sup&gt;h&lt;/sup&gt;</td>
<td>0</td>
<td>33</td>
</tr>
<tr>
<td>TN</td>
<td>79.7±0.73&lt;sup&gt;h&lt;/sup&gt;</td>
<td>37±0.53&lt;sup&gt;e&lt;/sup&gt;</td>
<td>25±0.43&lt;sup&gt;i&lt;/sup&gt;</td>
<td>47±0.84&lt;sup&gt;i&lt;/sup&gt;</td>
<td>12</td>
<td>22</td>
</tr>
<tr>
<td>EN</td>
<td>74.4±0.85&lt;sup&gt;i&lt;/sup&gt;</td>
<td>37±0.44&lt;sup&gt;e&lt;/sup&gt;</td>
<td>37±0.44&lt;sup&gt;d&lt;/sup&gt;</td>
<td>61±0.82&lt;sup&gt;j&lt;/sup&gt;</td>
<td>0</td>
<td>24</td>
</tr>
</tbody>
</table>

Values are mean ± SD of two independent analyses (n=2). Values with different superscript within a column are significantly different (p<0.05). CF-control flour, TF-traditional-nixtamalized flour, EF-ecological-nixtamalized flour, CN-control noodle flour, TN-traditional-nixtamalized noodle flour, EN-ecological-nixtamalized noodle flour.
Fig. 6.2: Pasting properties of nixtamalized flours and noodles. CF—control flour, TF—traditional-nixtamalized flour, EF—ecological-nixtamalized flour, CN—control noodle flour, TN—traditional-nixtamalized noodle flour, EN—ecological-nixtamalized noodle flour.
6.4.4. Instrumental colour measurement:

The colour values of noodle samples are presented in Table 6.4. There was decrease in lightness (L*) in noodle samples on nixtamalization. This may be attributed to the thermal breakdown of starch during processing. Due to traditional nixtamalization there was increase in redness (a*) in the noodle samples unlike in case of ecological nixtamalization. However, b* values which indicate yellowness (+ve) and blueness (-ve) shows a downward trend for TN and more so in case of EN. This may be due to the reduction of the yellow pigment-carotenoids on both types of nixtamalization.

Table 6.4: Instrumental colour analysis of the uncooked noodles

<table>
<thead>
<tr>
<th>Uncooked noodle sample</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dent maize</td>
<td>CN</td>
<td>47.57±0.63\textsuperscript{a}</td>
<td>9.67±0.07\textsuperscript{a}</td>
</tr>
<tr>
<td></td>
<td>TN</td>
<td>45.36±0.11\textsuperscript{b}</td>
<td>10.20±0.12\textsuperscript{b}</td>
</tr>
<tr>
<td></td>
<td>EN</td>
<td>36.99±1.16\textsuperscript{c}</td>
<td>8.21±0.18\textsuperscript{c}</td>
</tr>
<tr>
<td>Flint maize</td>
<td>CN</td>
<td>49.44±0.54\textsuperscript{d}</td>
<td>11.78±0.12\textsuperscript{d}</td>
</tr>
<tr>
<td></td>
<td>TN</td>
<td>48.48±0.20\textsuperscript{e}</td>
<td>12.75±0.07\textsuperscript{e}</td>
</tr>
<tr>
<td></td>
<td>EN</td>
<td>38.38±0.58\textsuperscript{f}</td>
<td>9.77±0.07\textsuperscript{a}</td>
</tr>
</tbody>
</table>

Values are mean ± SD of three independent analyses (n=3). Values with different superscript within a column are significantly different (p<0.05). CN-control noodle, TN-traditional-nixtamalized noodle, EN-ecological-nixtamalized noodle.

6.4.5. Proximate composition of the noodles:

The proximate composition of CF, nixtamalized flours (TF and EF) and their noodles (CN, TN and EN) is presented in Table 6.5. The moisture content slightly varied in the flours obtained with the nixtamalization methods. The moisture content of noodles was significantly lower (p<0.05) than their respective flours and varied within the range of 5.5-7.6%. There was no consistent variation in protein content in the nixtamalized and noodle flours with respect the control values. However, slight variation was observed in fat and ash contents. Fat
content had decreased on nixtamalization and further on noodle preparation, which indicates that the saponification might have occurred during nixtamalization and then on noodle processing. On the contrary, ash content had increased on nixtamalization and again on noodle processing probably due to the retention of bran and germ fractions. Our results corroborate with that of Bello-Pérez et al. (2015).

**Table 6.5**: Proximate composition of nixtamalized flours and noodles

<table>
<thead>
<tr>
<th>Sample</th>
<th>Moisture (%)</th>
<th>Protein (%)</th>
<th>Fat (%)</th>
<th>Ash (%)</th>
<th>Carbohydrate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dent Maize</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CF*</td>
<td>11.5±0.02a</td>
<td>10.8±0.20a</td>
<td>4.0±0.21a</td>
<td>1.3±0.06a</td>
<td>72.3±0.12a</td>
</tr>
<tr>
<td>TF</td>
<td>12.6±0.21b</td>
<td>12.8±0.05b</td>
<td>3.2±0.01b</td>
<td>1.6±0.04b</td>
<td>69.8±0.31b</td>
</tr>
<tr>
<td>EF</td>
<td>12.2±0.34b</td>
<td>13.7±0.11c</td>
<td>2.6±0.01c</td>
<td>1.8±0.04c</td>
<td>69.7±0.5b</td>
</tr>
<tr>
<td>CN</td>
<td>7.6±0.05c</td>
<td>11.2±0.07a</td>
<td>3.5±0.04d</td>
<td>2.1±0.02d</td>
<td>75.6±0.18c</td>
</tr>
<tr>
<td>TN</td>
<td>6.3±0.07d</td>
<td>13.4±0.24d</td>
<td>2.8±0.02c</td>
<td>2.2±0.03d</td>
<td>75.3±0.36c</td>
</tr>
<tr>
<td>EN</td>
<td>5.5±0.02e</td>
<td>12.2±0.12c</td>
<td>2.4±0.03c</td>
<td>1.9±0.04c</td>
<td>78.0±0.21d</td>
</tr>
<tr>
<td><strong>Flint Maize</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CF*</td>
<td>8.2±0.04f</td>
<td>14.4±1.1c</td>
<td>5.4±0.12c</td>
<td>1.4±0.05a</td>
<td>70.7±1.63c</td>
</tr>
<tr>
<td>TF</td>
<td>11.4±0.24a</td>
<td>15.8±1.4f</td>
<td>4.2±0.04a</td>
<td>1.6±0.04b</td>
<td>67.0±1.72f</td>
</tr>
<tr>
<td>EF</td>
<td>9.52±0.12g</td>
<td>14.5±0.7c</td>
<td>5.2±0.02c</td>
<td>1.3±0.0a</td>
<td>69.5±0.84b</td>
</tr>
<tr>
<td>CN</td>
<td>6.4±0.05d</td>
<td>12.5±0.2b,ce</td>
<td>4.8±0.07g</td>
<td>2.5±0.07e</td>
<td>73.7±0.30g</td>
</tr>
<tr>
<td>TN</td>
<td>6.2±0.03d</td>
<td>12.2±1.1e</td>
<td>3.7±0.01d</td>
<td>2.7±0.06f</td>
<td>75.0±1.2h</td>
</tr>
<tr>
<td>EN</td>
<td>7.1±0.03h</td>
<td>12.2±0.9e</td>
<td>4.2±0.22a</td>
<td>2.4±0.05e</td>
<td>74.1±1.2i</td>
</tr>
</tbody>
</table>

Values are mean ± SD of three independent analyses (n=3). Values with different superscript within a column are significantly different (p<0.05). CF-control flour, TF-traditional-nixtamalized flour, EF-ecological-nixtamalized flour, CN-control noodle flour, TN-traditional-nixtamalized noodle flour, EN-ecological-nixtamalized noodle flour.

*Values are actually from chapter 3, Table 3.1.

**6.4.6. Total phenolic and flavonoid content of nixtamalized flours and noodles:**

Fig. 6.3 shows the TFP and TBP content of flours and noodle samples. Significant differences were observed in traditional and ecological nixtamalization processes. TFF and TBF estimation were carried out
but the analysis resulted in no colour formation as was measured through spectrophotometer. Henceforth, the discussion of this section will be restricted to TFP, TBP and total phenolics (sum of TFP and TBP) content of nixtamalized flours and noodles. Both types of nixtamalization processes as well as noodle preparation process caused significant losses (p<0.05) of TFP and TBP. In the present study, the overall range of TFP, TBP and total phenolics was 0.83 to 23.5 µmole FAE/g of sample (10 to 297 mg of GAE/100 g of sample) in traditional nixtamalized flours, which is slightly higher than the range of values reported for masa by De la Parra *et al.* (2007) (28 to 198 mg of GAE/100 g of sample). However, total phenolic content of masa obtained through traditional nixtamalization as reported by Lopez-Martinez *et al.* (2011) for coloured maize (105 to 543 mg of GAE/100 g of sample), falls in the range of the obtained values of our samples (20 to 23.5 µmole FAE/g of sample or 254 to 298 mg of GAE/100 g of sample). Similarly, the overall range of TFP, TBP and total phenolics of flours obtained through ecological nixtamalization (1.31 to 29 µmole FAE/g of sample) was higher than that of traditional nixtamalization and corroborates with the reports of Rodriguez-Mendez *et al.* (2013). Hence, among the two nixtamalization processes, ecological nixtamalization resulted in higher retention of TFP, TBP and total phenolics in both the Dent and Flint genotypes. This can be explained by the fact that, in ecological nixtamalization the pH of the nejayote is about 7, which hinders the release of phenolics. On the other hand, pH of nejayote of traditional nixtamalization (~11 or more) causes weakening of ester bonds between the phenolics and the arabinoxylans (pentosans or gums) through hydrolysis to release the phenolics (Saulnier and Thibault, 1999; Cortes *et al.*, 2006; Campechano *et al.*, 2012).

A comparison of TN and EN with CF showed that Dent maize noodles prepared from traditional and ecological nixtamalized flours had the lowest retention of phenolics (40 and 64% for TN and EN,
respectively) whereas the Flint maize noodles produced with the same process retained 50 and 66% for TN and EN, respectively and therefore EN of Flint maize contained the highest amount of phenolic among the noodles prepared from nixtamalized flours. The loss in phenolics reported herein is consistent with De la Parra et al. (2007) and Mora-Rochin et al. (2010) who reported 35 to 44% reduction in total phenolics assayed in tortillas of five diverse maize genotypes. Del Pozo-Insfran et al. (2007) found that there were higher losses of total phenolics (54 to 89%) in nixtamalization than during the preparation of the tortillas. Such a significant difference (p<0.05) in phenolic losses between Dent and Flint maize can not only be attributed to the combined effect of alkaline and thermal processing during nixtamalization, but also to the difference in composition of the grains owing to the physical losses of the pericarp and leaching of phenolics into the nejayote. The cooking loss of phenolics for all the cooked noodle samples (CCN, CTN and CEN) was also analyzed (Fig. 6.3). It was found that the retention of phenolics in CTN and CEN of Dent maize is 35 and 58%, respectively (a further loss of 5 to 6% on cooking). The further loss of phenolics for TN and EN of Flint maize on cooking was only 2% which is significantly lower (p<0.05) than Dent maize noodles. However, there was 2-fold increase in TFP for CTN and CEN of Flint maize which indicates that bound phenolics may have been released from the noodles during cooking resulting in augmentation of free phenolics.
Fig. 6.3: Total phenolic and flavonoid content of nixtamalized flours and noodles. CF-control flour, TF-traditional-nixtamalized flour, EF-ecological-nixtamalized flour, CN-control noodle, TN-traditional-nixtamalized noodle, EN-ecological-nixtamalized noodle, CCN-cooked control noodle, CTN-cooked traditional-nixtamalized noodle, CEN-cooked ecological-nixtamalized noodle.
6.4.7. Composition and concentration of individual phenolic compounds in nixtamalized flours and noodles

Most of the studies enumerating the effect of nixtamalization on phenolic compounds emphatically explained the fate of FA on processing (Ayala-Soto et al., 2014; Del Pozo-Insfran et al., 2007; Del Parra et al., 2007; Gutiérrez-Uribe et al., 2010; Mora-Rochin et al., 2010). However, maize being an important source of other phenolic acids as well, it was felt necessary that a complete profile of free and bound phenolic composition after traditional and ecological nixtamalization be investigated. VA, CA, p-CA and FA were found to be present as free compounds in nixtamalized flour and noodles of nixtamalized Dent and Flint maize (Fig. 6.4, Table 6.6), whereas p-HA, SA and PA were additionally present along with the previous ones as bound acids (Fig. 6.5, Table 6.7). Free VA content of Dent maize was significantly (p<0.05) higher than Flint maize and it’s retention was higher in EF (34%) than TF (24%) and their respective noodles (23 and 31%). Free CA and p-CA which were present in traces in CFs, were almost lost after nixtamalization. There was significantly (p<0.05) higher retention of free FA on both types of nixtamalization for Flint (55%) than Dent maize (34%) and so also bound FA (57% and 52%, respectively). Similarly for all the studied compounds, their retention was higher in Flint maize than Dent maize after nixtamalization. Nevertheless, the results showed that during both types of nixtamalization free and bound phenolic compounds are lost in varying proportions. Observations of De la Parra et al. (2007), Gutiérrez-Uribe et al. (2010) and Mora-Rochin et al. (2010) for free FA are in contrary to ours, as they had shown that bound FA becomes free after nixtamalization resulting in increase in free FA by many folds.
Fig. 4.4: HPLC chromatograms of free phenolics (at 280 nm) showing separation of free phenolic acids in flour and noodle samples of Dent and Flint maize. CF-control flour, TF-traditional-nixtamalized flour, EF-ecological-nixtamalized flour, CN-control noodle, TN-traditional-nixtamalized noodle, EN-ecological-nixtamalized noodle. 1= vanillic, 2= caffeic, 3= p-coumaric, 4= ferulic.
Fig. 4.5: HPLC chromatograms of bound phenolics (at 280 nm) showing separation of free phenolic acids in flour and noodle samples of Dent and Flint maize. CF-control flour, TF-traditional-nixtamalized flour, EF-ecological-nixtamalized flour, CN-control noodle, TN-traditional-nixtamalized noodle, EN-ecological-nixtamalized noodle. 1= p-hydroxybenzoic, 2= vanillic, 3= syringic, 4= caffeic, 5= p-coumaric, 6= ferulic, 7= protocatechuric.
Table 6.6: Concentration (µg/g of dry sample) of free phenolic acids in nixtamalized flours and noodles

<table>
<thead>
<tr>
<th>Sample</th>
<th>Phenolic acids</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vanillic</td>
<td>Caffeic</td>
<td>p-coumaric</td>
<td>Ferulic</td>
</tr>
<tr>
<td>Dent Maize CF*</td>
<td>28.6±0.9a</td>
<td>4.2±0.16a</td>
<td>4.8±0.22a</td>
<td>50.0±1.4a</td>
</tr>
<tr>
<td>TF</td>
<td>6.8±0.32b</td>
<td>nf</td>
<td>1.10±0.07b</td>
<td>13.21±0.42b</td>
</tr>
<tr>
<td>EF</td>
<td>9.85±0.54c</td>
<td>1.66±0.02b</td>
<td>1.53±0.05c</td>
<td>21.23±0.62c</td>
</tr>
<tr>
<td>CN</td>
<td>8.17±0.47d</td>
<td>1.24±0.02c</td>
<td>1.27±0.07b</td>
<td>18.28±0.74d</td>
</tr>
<tr>
<td>TN</td>
<td>6.5±0.24b</td>
<td>nf</td>
<td>0.54±0.02d</td>
<td>11.41±0.54e</td>
</tr>
<tr>
<td>EN</td>
<td>8.82±0.63c,d</td>
<td>1.21±0.03c</td>
<td>1.48±0.1c</td>
<td>18.43±0.92d</td>
</tr>
<tr>
<td>Flint Maize CF</td>
<td>2.62±0.08e</td>
<td>2.21±0.03d</td>
<td>2.11±0.17e</td>
<td>46.29±1.21f</td>
</tr>
<tr>
<td>TF</td>
<td>1.20±0.08f</td>
<td>nf</td>
<td>nf</td>
<td>23.57±0.88g</td>
</tr>
<tr>
<td>EF</td>
<td>1.21±0.07f</td>
<td>nf</td>
<td>nf</td>
<td>27.48±0.93h</td>
</tr>
<tr>
<td>CN</td>
<td>nf</td>
<td>nf</td>
<td>1.11±0.04b</td>
<td>24.24±0.62g,i</td>
</tr>
<tr>
<td>TN</td>
<td>nf</td>
<td>nf</td>
<td>nf</td>
<td>20.46±0.54c</td>
</tr>
<tr>
<td>EN</td>
<td>nf</td>
<td>nf</td>
<td>nf</td>
<td>25.44±0.84i</td>
</tr>
</tbody>
</table>

Values are mean ± SD of two independent analyses (n=2). Values with different superscript within a column are significantly different (p<0.05). CF-control flour, TF-traditional-nixtamalized flour, EF-ecological-nixtamalized flour, CN-control noodle, TN-traditional-nixtamalized noodle, EN-ecological-nixtamalized noodle. *Values are actually from chapter 3, Table 3.2. nf = not found.
<table>
<thead>
<tr>
<th>Sample</th>
<th>p-hydroxybenzoic</th>
<th>Vanillic</th>
<th>Syringic</th>
<th>Caffeic</th>
<th>p-coumaric</th>
<th>Ferulic</th>
<th>Proto-catechuric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dent Maize</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CF*</td>
<td>185.2±11.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>196.3±12.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.24±0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>20.08±1.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>460.6±25.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.12±0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>TF</td>
<td>82.33±4.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>86.44±4.51&lt;sup&gt;c,d&lt;/sup&gt;</td>
<td>1.48±0.07&lt;sup&gt;b,d&lt;/sup&gt;</td>
<td>8.48±0.82&lt;sup&gt;b&lt;/sup&gt;</td>
<td>205.5±14.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.73±0.08&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>EF</td>
<td>107.8±6.62&lt;sup&gt;c&lt;/sup&gt;</td>
<td>113.2±7.24&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.62±0.05&lt;sup&gt;c,d&lt;/sup&gt;</td>
<td>10.73±0.86&lt;sup&gt;c&lt;/sup&gt;</td>
<td>270.7±13.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.68±0.10&lt;sup&gt;c&lt;/sup&gt;</td>
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</tr>
<tr>
<td>CN</td>
<td>90.28±5.18&lt;sup&gt;b&lt;/sup&gt;</td>
<td>93.89±5.42&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.55±0.05&lt;sup&gt;d&lt;/sup&gt;</td>
<td>8.82±0.72&lt;sup&gt;b&lt;/sup&gt;</td>
<td>215.5±15.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.88±0.09&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>TN</td>
<td>74.81±4.71&lt;sup&gt;c&lt;/sup&gt;</td>
<td>80.28±6.21&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.22±0.04&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.43±0.66&lt;sup&gt;b&lt;/sup&gt;</td>
<td>190.3±12.5&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.82±0.05&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>EN</td>
<td>118.3±7.4&lt;sup&gt;d&lt;/sup&gt;</td>
<td>128.5±6.44&lt;sup&gt;e&lt;/sup&gt;</td>
<td>2.28±0.17&lt;sup&gt;e&lt;/sup&gt;</td>
<td>14.42±0.86&lt;sup&gt;d&lt;/sup&gt;</td>
<td>302.8±19.5&lt;sup&gt;e&lt;/sup&gt;</td>
<td>1.82±0.07&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>Flint Maize</td>
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<tr>
<td>CF</td>
<td>21.53±0.98&lt;sup&gt;a&lt;/sup&gt;</td>
<td>145.4±8.2&lt;sup&gt;e&lt;/sup&gt;</td>
<td>210.5±11.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.4±0.24&lt;sup&gt;f&lt;/sup&gt;</td>
<td>37.37±1.52&lt;sup&gt;e&lt;/sup&gt;</td>
<td>251.6±12.4&lt;sup&gt;f&lt;/sup&gt;</td>
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<tr>
<td>TF</td>
<td>11.72±0.83&lt;sup&gt;b&lt;/sup&gt;</td>
<td>72.33±3.7&lt;sup&gt;c&lt;/sup&gt;</td>
<td>102.6±5.24&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.28±0.31&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.62±1.12&lt;sup&gt;f&lt;/sup&gt;</td>
<td>129.1±7.61&lt;sup&gt;g&lt;/sup&gt;</td>
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<tr>
<td>EF</td>
<td>13.92±0.73&lt;sup&gt;c&lt;/sup&gt;</td>
<td>89.92±4.86&lt;sup&gt;b&lt;/sup&gt;</td>
<td>130.2±7.21&lt;sup&gt;e&lt;/sup&gt;</td>
<td>4.12±0.31&lt;sup&gt;g&lt;/sup&gt;</td>
<td>24.42±1.43&lt;sup&gt;g&lt;/sup&gt;</td>
<td>158.9±10.5&lt;sup&gt;h&lt;/sup&gt;</td>
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<td>84.42±3.58&lt;sup&gt;b&lt;/sup&gt;</td>
<td>121.1±7.3&lt;sup&gt;e&lt;/sup&gt;</td>
<td>3.57±0.3&lt;sup&gt;h&lt;/sup&gt;</td>
<td>22.28±1.21&lt;sup&gt;a,g&lt;/sup&gt;</td>
<td>147.2±7.21&lt;sup&gt;i&lt;/sup&gt;</td>
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<tr>
<td>TN</td>
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<td>74.52±3.7&lt;sup&gt;c&lt;/sup&gt;</td>
<td>111.2±6.23&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.32±0.45&lt;sup&gt;g&lt;/sup&gt;</td>
<td>18.82±0.92&lt;sup&gt;f&lt;/sup&gt;</td>
<td>141.58±8.82&lt;sup&gt;i&lt;/sup&gt;</td>
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<tr>
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<td>102.8±5.42&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7±7.86&lt;sup&gt;f&lt;/sup&gt;</td>
<td>3.32±0.44&lt;sup&gt;a&lt;/sup&gt;</td>
<td>26.32±1.27&lt;sup&gt;g&lt;/sup&gt;</td>
<td>174.9±8.46&lt;sup&gt;j&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

Values are mean ± SD of two independent analyses (n=2). Values with different superscript within a column are significantly different (p<0.05). CF-control flour, TF-traditional-nixtamalized flour, EF-ecological-nixtamalized flour, CN-control noodle, TN-traditional-nixtamalized noodle, EN-ecological-nixtamalized noodle. nf= not found, *Values are actually from chapter 3, Table 3.3.
6.4.8. Antioxidant capacities of nixtamalized flours and noodles:

There are limited studies in literature on the antioxidant capacity of foods exerted by intrinsic hydrophilic and lipophilic chemical components. In the present study the hydrophilic antioxidant capacities of nixtamalized flours, noodles and cooked noodles were evaluated and presented in Table 6.8. The antioxidant capacities significantly (p<0.05) decreased after nixtamalization (TF and EF) and further on noodle preparation (TN and EN) from the maize samples. A slight decrease in the antioxidant capacities were also observed on cooking the noodles. The loss in antioxidant capacities were higher (p<0.05) for Dent maize on processing, whereas the process of traditional nixtamalization caused higher degree of loss in antioxidant capacities for both the maize genotypes. Hence, the EF and EN of Flint maize had the highest retention of antioxidant capacities. The decrease in antioxidant capacities is presumably in consistent with the decrease in free and bound phenolics on nixtamalization and noodle preparation. Data from the USDA on 100 different processed foods showed that the cooking process can increase or decrease the antioxidant capacity of foods depending on the nature and molecular structure of the antioxidant compound (Wu et al., 2004). In the present study heat treatments involved in nixtamalization and processing of noodles affected the antioxidant activity. However, the extracts of free phenolics from CTN and CEN of Flint maize demonstrated higher antioxidant capacities owing to their increased free phenolic content resulted from bond ones. A similar observation of higher antioxidant capacity on baking masa into tortillas was observed by De la Parra et al. (2007). Our results indicated that the proposed development of noodles through nixtamalization process was instrumental in retaining higher levels of antioxidative phenolics and antioxidant capacities in noodles. Our results clearly demonstrated the benefits of consumption of whole grain products and use of nixtamalization process to develop other functional foods from maize.
Table 6.8: Antioxidant capacities of nixtamalized flours, noodles and cooked noodles

<table>
<thead>
<tr>
<th>Sample</th>
<th>CF</th>
<th>TF</th>
<th>EF</th>
<th>CN</th>
<th>TN</th>
<th>EN</th>
<th>CCN</th>
<th>CTN</th>
<th>CEN</th>
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<tbody>
<tr>
<td></td>
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<td>DPPH radical scavenging capacity</td>
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<tr>
<td>Dent</td>
<td></td>
<td></td>
<td></td>
<td>ABTS radical scavenging capacity</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>H₂O₂ scavenging capacity</td>
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</tr>
</tbody>
</table>

- **Dent**
  - **Free**
    - CF: 1.23±0.06
    - TF: 0.40±0.02
    - EF: 0.58±0.01
    - CN: 0.46±0.02
    - TN: 0.38±0.02
    - EN: 0.49±0.04
    - CCN: 0.32±0.01
    - CTN: 0.33±0.01
    - CEN: 0.39±0.02
  - **Bound**
    - CF: 2265±160
    - TF: 1049±95
    - EF: 1362±101
    - CN: 1167±85
    - TN: 969±85
    - EN: 1546±96
    - CCN: 1085±73
    - CTN: 934±65
    - CEN: 1327±84
  - **Total**
    - CF: 2265±160
    - TF: 1049±95
    - EF: 1363±101
    - CN: 1167±85
    - TN: 969±85
    - EN: 1546±96
    - CCN: 1085±73
    - CTN: 934±65
    - CEN: 1327±84

- **Flint**
  - **Free**
    - CF: 1.10±0.06
    - TF: 0.56±0.02
    - EF: 0.57±0.04
    - CN: 0.46±0.02
    - TN: 0.41±0.01
    - EN: 0.45±0.02
    - CCN: 0.35±0.01
    - CTN: 0.90±0.04
    - CEN: 0.94±0.03
  - **Bound**
    - CF: 2619±123
    - TF: 1356±85
    - EF: 1681±96
    - CN: 1535±45
    - TN: 1388±76
    - EN: 1825±82
    - CCN: 1458±67
    - CTN: 1124±63
    - CEN: 1635±77
  - **Total**
    - CF: 2620±123
    - TF: 1356±85
    - EF: 1681±96
    - CN: 1535±45
    - TN: 1388±76
    - EN: 1825±82
    - CCN: 1458±67
    - CTN: 1124±63
    - CEN: 1635±77

- **Dent**
  - **Free**
    - CF: 1.31±0.07
    - TF: 0.41±0.02
    - EF: 0.60±0.04
    - CN: 0.47±0.01
    - TN: 0.39±0.01
    - EN: 0.50±0.02
    - CCN: 0.37±0.01
    - CTN: 0.32±0.01
    - CEN: 0.42±0.02
  - **Bound**
    - CF: 1092±84
    - TF: 501±32
    - EF: 652±42
    - CN: 558±43
    - TN: 463±24
    - EN: 740±84
    - CCN: 478±56
    - CTN: 423±55
    - CEN: 692±72
  - **Total**
    - CF: 1093±84
    - TF: 501±32
    - EF: 652±42
    - CN: 558±43
    - TN: 463±24
    - EN: 740±84
    - CCN: 478±56
    - CTN: 423±55
    - CEN: 692±72

- **Flint**
  - **Free**
    - CF: 1.18±0.06
    - TF: 0.57±0.04
    - EF: 0.58±0.03
    - CN: 0.47±0.02
    - TN: 0.41±0.01
    - EN: 0.45±0.01
    - CCN: 0.38±0.01
    - CTN: 0.75±0.04
    - CEN: 0.82±0.06
  - **Bound**
    - CF: 1002±76
    - TF: 507±35
    - EF: 631±41
    - CN: 576±45
    - TN: 519±37
    - EN: 686±66
    - CCN: 536±54
    - CTN: 495±34
    - CEN: 614±45
  - **Total**
    - CF: 1003±76
    - TF: 507±35
    - EF: 631±41
    - CN: 576±45
    - TN: 519±37
    - EN: 686±66
    - CCN: 536±54
    - CTN: 496±34
    - CEN: 615±45

- **Dent**
  - **Free**
    - CF: 19.3±0.6
    - TF: 5.07±0.3
    - EF: 7.87±0.4
    - CN: 6.0±0.5
    - TN: 4.83±0.3
    - EN: 6.47±0.4
    - CCN: 5.24±0.3
    - CTN: 3.24±0.2
    - CEN: 5.56±0.4
  - **Bound**
    - CF: 153±7
    - TF: 65.4±2.8
    - EF: 86.6±3.4
    - CN: 73.4±4.2
    - TN: 60.1±3.8
    - EN: 99.0±4.0
    - CCN: 67.5±3.1
    - CTN: 57.8±2.9
    - CEN: 86.5±3.2
  - **Total**
    - CF: 172±7.6
    - TF: 70±3
    - EF: 94±4
    - CN: 79±5
    - TN: 65±4
    - EN: 105±4
    - CCN: 73±3
    - CTN: 60±3
    - CEN: 92±4

- **Flint**
  - **Free**
    - CF: 20.3±0.8
    - TF: 8.81±0.6
    - EF: 8.99±0.8
    - CN: 7.06±0.4
    - TN: 6.13±0.3
    - EN: 6.77±0.4
    - CCN: 5.24±0.2
    - CTN: 8.86±0.6
    - CEN: 8.78±0.4
  - **Bound**
    - CF: 160±7.3
    - TF: 77.8±3.4
    - EF: 97.6±5.6
    - CN: 88.7±4.6
    - TN: 79.7±4.3
    - EN: 106±5.2
    - CCN: 86.7±3.4
    - CTN: 78.6±4.7
    - CEN: 98.6±7.3
  - **Total**
    - CF: 180±8
    - TF: 87±4
    - EF: 106±6
    - CN: 96±5
    - TN: 86±5
    - EN: 113±6
    - CCN: 92±4
    - CTN: 87±5
    - CEN: 107±8
Table 6.8 continued.....

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<th>Inhibition of lipid peroxidation capacity</th>
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<td>Bound</td>
<td>Total</td>
</tr>
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<td>74±1c</td>
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Values are mean ± SD of three independent analyses (n=3). Values with different superscript within a row is significantly different (p<0.05).
6.4.9. Sensory analysis of noodles:

Based on the physico-chemical and phytochemical results, the best three types of noodles *viz.* EN of Dent and Flint maize and TN of Flint were evaluated (Fig. 6.4). A commercial wheat noodle sample was also analyzed alongside. Results showed that after wheat noodle, EN of Flint maize received higher scores than others. EN of Dent maize was awarded least sensory scores, particularly on ‘distinct strands’ and ‘firmness’. The overall acceptability of wheat noodle was 7.9, whereas that of EN and TN of Flint maize was 6.7 and 6.5, respectively. Results showed that noodle obtained from ecological nixtamalized flour of Flint maize was most acceptable among the maize noodles analyzed.
Fig. 6.6: Whole grain maize noodles. A- Noodle (cooked) from ecological nixtamalized Dent maize, B- Noodle (cooked) from traditional nixtamalized Flint maize, C- Noodle (cooked) from ecological nixtamalized Flint maize

Fig. 6.7: Sensory analysis of noodles. EN- ecological-nixtamalized noodle, TN- traditional-nixtamalized noodle.