Non-traditional Grains in Precooked Pasta Using Extrusion: Physico-Chemical Properties and Resistant Starch

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Sorghum in the 21st Century Food, Feed and Fuel in a Rapidly Changing World
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Is there space for ancient grains in pasta?
Traditional Pasta
Sorghum Pasta
Properties of sorghum kafirins

- ~70% of sorghum proteins; prolamins
- Hydrophobic; Soluble in non-polar solvents (60% t-Butanol; 70% Ethanol)
- Extracted with SDS
- pH 10 (typical); or very strong acid (glacial acetic acid)
- $M_w$ of kafirins
  - $\alpha$: 23-25 kDa; 66-84% of kafirins; easily digestible
  - $\beta$: ~18 kDa; 8-13% of kafirins; highly crosslinked
  - $\gamma$: ~20 kDa; 9-12% of kafirins; highly crosslinked
  - $\delta$: ~13 kDa; not well-characterized
Sorghum protein body schematic

Interspersed glutelin matrix material coating the protein body

Outer “shell” composed mainly of crosslinked β- and γ-kafirins

Interior composed mainly of α-kafirin
Protein bodies and starch granules are embedded in the glutelin matrix.
Sorghum Protein Digestibility

- Raw, condensed tannin-free, white sorghum:
  - 55.8 % (raw, whole grain)
  - 67.4 % (raw, decorticated)
  - 36.6 % (boiled, whole grain)
  - 39.4 % (boiled, decorticated)

Wet cooking reduces protein digestibility.
Extrusion/ Dry Cooking improves *In Vitro* Protein Digestibility (IVPD)

- **Extrusion** -
  
  25% moisture, 200°C: increased IVPD to 75% of whole sorghum flour  
  (Fapohuwo, 1987)

  @ < 20% moisture, 177°C: increased IVPD from 61 to 70% of whole sorghum flour  
  (Hamaker, 1994)

- **Decortication & extrusion** increased IVPD to 79%  
  (Mertz, 1984)

- Increased *in vivo* protein digestibility  
  (MacLean, 1983)
Raw Sorghum Flour

Diagram showing the protein bodies and starch in raw sorghum flour.

- **Protein Bodies**
- **Starch**
- **Protein Matrix**
Raw Sorghum Flour

Protein Bodies

10 µm
Confocal Laser Scanning Microscopy (CLSM) is a useful tool in explaining the structural changes underlying the differences in digestibility.

- **38% digestibility**
  - 14% In-barrel moisture
  - Extrusion energy (SME) = 1336 kJ/kg

- **66% digestibility**
  - 32% In-barrel moisture
  - Extrusion energy (SME) = 329 kJ/kg
Physical Changes in Starch During Cooking

Crystalline Structure

Non-Crystalline Structure

Raw/Native

Gelatinized

Swollen Granules
Physical Changes in Starch During Cooking

Swollen Granules → Dispersed → Depolymerized → Soluble

Degraded
Screw Terminology

Double Flight

Single Flight

Figure 1: Screw terminology (courtesy of Wenger Manufacturing Co., Sabetha, KS).
## Extruder Classification By Process/ Product

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pasta Press</th>
<th>High pressure forming extruder</th>
<th>Low shear cooking extruder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed moisture (% wb)</td>
<td>32</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>Max. product temperature (°C)</td>
<td>50</td>
<td>80</td>
<td>150</td>
</tr>
<tr>
<td>Screw dia to flight height ratio (D/H)</td>
<td>3-4</td>
<td>4.5</td>
<td>7-15</td>
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<tr>
<td>Screw speed (rpm)</td>
<td>50-60</td>
<td>100-150</td>
<td>150-200</td>
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<tr>
<td>Shear rate (1 s⁻¹)</td>
<td>5</td>
<td>10</td>
<td>20-100</td>
</tr>
<tr>
<td>Mechanical energy (MJ kg⁻¹)</td>
<td>0.11</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>Steam injection (MJ kg⁻¹)</td>
<td>0</td>
<td>0</td>
<td>0-0.11</td>
</tr>
<tr>
<td>Barrel heat (MJ kg⁻¹)</td>
<td>-0.04</td>
<td>-0.04</td>
<td>0-0.11</td>
</tr>
<tr>
<td>Net energy input (MJ kg⁻¹)</td>
<td>0.07</td>
<td>0.10</td>
<td>0.25-0.36</td>
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<tr>
<td>Product type</td>
<td>Pasta, fabricated chips</td>
<td>RTE cereal pellets, 3G snacks</td>
<td>Soft-moist products, pregel starch, soup bases</td>
</tr>
</tbody>
</table>
Fig. 12. Extrusion worm. Note the three-finned type in the terminal part of the worm (courtesy of M.G. Braibanti S.p.A., Milan).
<table>
<thead>
<tr>
<th>Variable</th>
<th>Collet extruder</th>
<th>High shear cooking extruder</th>
<th>Twin screw cooking extruder</th>
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<tr>
<td>Feed moisture (% wb)</td>
<td>14-16</td>
<td>15-25</td>
<td>15-40</td>
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<tr>
<td>Max. product temperature (°C)</td>
<td>200</td>
<td>180</td>
<td>80-200</td>
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<tr>
<td>Screw dia to flight height ratio (D/H)</td>
<td>9</td>
<td>7</td>
<td></td>
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<tr>
<td>Screw speed (rpm)</td>
<td>300</td>
<td>350-500</td>
<td>200-500</td>
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<td>Shear rate (1 s⁻¹)</td>
<td>140</td>
<td>165</td>
<td>100-200</td>
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<tr>
<td>Mechanical energy (MJ kg⁻¹)</td>
<td>0.36</td>
<td>0.40</td>
<td>0.14-0.40</td>
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<tr>
<td>Steam injection (MJ kg⁻¹)</td>
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<td>0-0.10</td>
<td>0-0.20</td>
</tr>
<tr>
<td>Barrel heat (MJ kg⁻¹)</td>
<td>0</td>
<td>(-0.11)-0.05</td>
<td>(-0.20)-0.10</td>
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<tr>
<td>Net energy input (MJ kg⁻¹)</td>
<td>0.36</td>
<td>0.29-0.51</td>
<td>0.03-0.51</td>
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<tr>
<td>Product type</td>
<td>Puffed snacks</td>
<td>Puffed snacks, RTE cereals, textured protein, expanded petfood, aquatic feed</td>
<td>Puffed snacks, RTE cereals, fabricated chips, 3G snacks, pre-cooked pasta</td>
</tr>
</tbody>
</table>
Experimental Methods: Pre-Cooked Pasta

Pilot-scale extrusion

- Wenger twin screw extruder TX-52 (30 HP); 52mm screw dia
- Dry feed rate = 60 kg/h
- Pre-conditioning: steam and water addition in
- In-barrel moisture = 40-49%
- In-line cooling using vacuum
- Rotini die with 19 openings
- Drying: Wenger double-pass dryer 70°C for 40 min followed by cooling
Twin Screw Extruder Set-up with Vacuum Cooling for Pre-Cooked Pasta
Experimental Methods: Pre-Cooked Pasta

Pasta physico-chemical quality analyses

**Cooking loss** (AACC Approved Method 66–50; AACC, 2000; 5 minutes cooking)

\[
\text{Cooking loss(\%) = } \frac{\text{Dried weight of residue}}{\text{Weight of sample}} \times 100
\]

**Water absorption**

\[
\text{Water absorption \%} = \left( \frac{\text{(Cooked product weight} - \text{Dry product weight)}}{\text{Dry product weight}} \right) \times 100
\]

**Differential scanning calorimetry**

\[
\text{Starch gelatinization \%} = \left( \frac{\Delta H_{\text{raw}} - \Delta H_{\text{extruded}}}{\Delta H_{\text{raw}}} \right) \times 100
\]

where, \(\Delta H_{\text{raw}}\) = enthalpy of raw binary blend, \(\Delta H_{\text{extruded}}\) = enthalpy of extruded binary blend
Pasta physico-chemical quality analyses (continued)

Textural properties

• TA. XT plus texture analyzer (Stable Micro Systems, Surrey, UK)
• Strength of uncooked pasta - 3-point bend test: force (kg) measured to determine the break strength
• Firmness of cooked pasta – texture profile analysis AACC Approved Method 66–50 (AACC, 1999). A two-cycle compression test; maximum positive force at first compression
• Stickiness of cooked pasta – texture profile analysis AACC Approved Method 66–50 (AACC, 1999). maximum negative peak force to separate the probe from the sample surface upon retraction after first compression.

Resistant starch determination

Using resistant starch assay kit supplied by Megazyme International Ireland Ltd. (AACC 2001; AOAC 2000 standard methods)
Proximate analysis of grains

Proximate analysis of raw materials

- Millet Flour
- Teff Flour
- Sorghum Flour
- Semolina

Dehulled proso millets (*Panicum miliaceum L.*) flour
Whole grain ivory (white) teff (*Eragrostis tef*) flour

Decorticated white sorghum (*Sorghum bicolor L. Moench*) flour

- Crude Protein
- Crude Fiber
- Fat
- Ash
- Total Starch
## I - Process and Formulation ‘Optimization’

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Control</th>
<th>Low moisture</th>
<th>Mid moisture</th>
<th>High moisture/Low lipids</th>
<th>Mid lipids</th>
<th>High lipids</th>
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<tbody>
<tr>
<td>Semolina</td>
<td>98.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorghum Flour</td>
<td>98.5</td>
<td>98.5</td>
<td>98.5</td>
<td>98.5</td>
<td>98.0</td>
<td>97.5</td>
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<td>Mono-glycerides</td>
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<td>0.5</td>
<td>1.0</td>
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<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
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<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<tr>
<td>In-barrel moisture</td>
<td>47</td>
<td>40</td>
<td>44</td>
<td>48</td>
<td>48</td>
<td>48</td>
</tr>
</tbody>
</table>

## II – Different Ancient Grains - Sorghum, Millet and Teff

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Control</th>
<th>Sorghum</th>
<th>Teff</th>
<th>Teff + Starch</th>
<th>Millet</th>
<th>Millet + Starch</th>
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</thead>
<tbody>
<tr>
<td>Semolina</td>
<td>98</td>
<td></td>
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<tr>
<td>Sorghum Flour</td>
<td></td>
<td>98</td>
<td>98</td>
<td>88</td>
<td>98</td>
<td>88</td>
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<tr>
<td>Teff Flour</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Millet Flour</td>
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<td>98</td>
<td>88</td>
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<td>Corn starch</td>
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<tr>
<td>Mono-glycerides</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td>Salt</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>In-barrel moisture</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
</tr>
</tbody>
</table>
Cooking Loss of Commercial Semolina Pasta

Cooking loss = 3.2%  
(12 minute cooking time)
Cooking Loss of Pre-Cooked Pasta - I

![Graph 1](In-barrel moisture (%) vs. Solid Loss (%)

- Red line: sorghum pasta
- Green line: Control wheat

![Graph 2](Mono-glycerides (%) vs. Solid Loss (%)

- Red line: sorghum pasta
- Green line: Control wheat

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Firmness of Pre-cooked Pasta - I

![Bar chart showing firmness of sorghum pasta and control wheat at different moisture levels (40%, 44%, 48%).]  

![Bar chart showing firmness of sorghum pasta and control wheat at different mono-glycerides levels (0.5%, 1.0%, 1.5%).]

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Firmness of Pre-cooked Pasta - II

![Graph showing firmness of pre-cooked pasta](chart)

- **Sorghum+MG (1%)**
- **Teff+MG (1%)**
- **Millet+MG (1%)**

**Y-axis**: Force (kg)

**X-axis**: Alternate grains, control wheat

**Legend**: Alternate grains, control wheat
Stickiness of Pre-cooked Pasta - I

In-barrel moisture (%)

Mono-glycerides (%)

DO NOT COPY
Stickiness of Pre-cooked Pasta - II

-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
-0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7

<table>
<thead>
<tr>
<th>Force (kg)</th>
<th>Alternate grains</th>
<th>Control wheat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorghum+MG (1%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teff+MG (1%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Millet+MG (1%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DO NOT COPY
Thermal characterization

Raw semolina
- T-onset (57.4 °C, Δh≈8.9 J/g)
- T-peak
- T-completion

Raw teff flour
- T-onset (69.1 °C, Δh≈10.27 J/g)
- T-peak
- T-completion

Raw sorghum flour
- T-onset (67.8 °C, Δh≈9.8 J/g)
- T-peak
- T-completion

Raw millet flour
- T-onset (69.8 °C, Δh≈7.2 J/g)
- T-peak
- T-completion
Thermal Characterization Using DSC

**Completely gelatinized semolina pasta**
- No Peak

**Completely gelatinized sorghum pasta**
- T-onset (54.6 °C, Δh≈ 0.96 J/g)
- T-peak
- T-completion

**~90% gelatinized sorghum pasta**
- T-onset (54.6 °C, Δh≈ 0.96 J/g)

**Completely gelatinized millet pasta**
- No Peak

**~95% gelatinized millet pasta**
- T-onset (55.5 °C, Δh≈ 0.52 J/g)
- T-peak
- T-completion
Pasting Properties Using RVA

RVA response - understanding starch degradation at low and high process moisture conditions

- Sorghum low moisture 40%
- Sorghum high moisture 48%

RVA response - understanding starch degradation at low and high mono-glyceride concentration

- Sorghum 0.5% mono-glycerides
- Sorghum 1.5% mono-glycerides
Resistant Starch of Processed Sorghum

Take away: RS content increased with increase in tannin content but all values were less than 1% under high energy extrusion conditions. Jury still out for low intensity processes.
Conclusions

1. Quality of pre-cooked pasta based on sorghum (and to some extent millets and teff) was comparable to semolina-based pre-cooked pasta and even traditional uncooked semolina pasta obtained from the market; quality can be related to grain composition, starch degradation and gelatinization levels.

2. High extrusion in-barrel moisture (48%) and 1% monoglycerides resulted in good quality gluten-free pre-cooked pasta.

3. Low extrusion in-barrel moisture led to excessive starch degradation, cooking loss and poor quality pre-cooked pasta product.

4. High monoglyecride concentration resulted in poorer quality pre-cooked pasta possibly due to incomplete ‘cooking’.

5. Sorghum -based precooked pasta was of the best quality while millet pasta was poorest in cooking quality, and visual and textural attributes.

6. High concentration of tannins increased the resistant starch although it was less than 1% for all treatments. More studies need to be done for low energy processes.