Milling technology for cereals

QA/QC on flour fortification, Kampala, 24-05-2016

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Cereals
Cereal grains

- **Ceres**

- **What are cereals?**
  - Grass family (*Gramineae*)
  - One seeded fruits
    - **Caryopsis** = kernel = grain
    - Germ
    - Endosperm
    - Bran: seed coat and fruit coat
    - Developes in glume (chaff, husk)
  - Easy to grow, high yield, stable, storage

24/05/2016
Cereal grains

Regnum: Eucarya
Subregnum: Chlorobionta
Phylum: Streptophyta
Subphylum: Spermatophytina (seed plants)
Classis: Magnoliopsida (flowering plants)
Subclassis: Liliidae (monocots)
Ordo: Poales
Familia: Poaceae (Gramineae)
Subfamilia: Poideae
Genus: Triticum, Secale, Hordeum, Avena
Species: durum, turgidum, aestivum, spelta

Aegilops squarrosa

wheat, rye, barley, oat, rice, maize, sorghum, pearl millet, true millet, teff, finger millet

pseudo-cereals

Ordo Caryophyllales/Polygonales
Familia Amaranthaceae: Amaranthus paniculatus (amaranth)
Familia Chenopodiaceae: Chenopodium quinoa (quinoa)
Familia Polygonaceae: Fagopyrum esculentum (buckwheat)
Ordo Malpighiales
Familia Euphorbiaceae: Manihot esculentum (cassava)

Rosidae (dicots)
Cereals in the world

- Annual production of major cereals in 2010/2014 (source: faostat.fao.org)

<table>
<thead>
<tr>
<th>Cereal</th>
<th>2010 (Million tonnes)</th>
<th>2014 (Million tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>1021</td>
<td>844</td>
</tr>
<tr>
<td>Rice (paddy)</td>
<td>672</td>
<td>741</td>
</tr>
<tr>
<td>Wheat</td>
<td>651</td>
<td>728</td>
</tr>
<tr>
<td>Barley</td>
<td>123</td>
<td>144</td>
</tr>
<tr>
<td>Sorghum</td>
<td>56</td>
<td>68</td>
</tr>
<tr>
<td>Millet</td>
<td>29</td>
<td>28</td>
</tr>
<tr>
<td>Triticale</td>
<td>13</td>
<td>17</td>
</tr>
<tr>
<td>Rye</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>Buckwheat</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>
Nutritional importance of cereals

• Macronutrients:
  ◦ Carbohydrates (50-80%)
  ◦ Staple food
  ◦ Digestable: starch
  ◦ Undigestable: dietary fiber
  ◦ Proteins (8-15%)
  ◦ Lipids (1.5-7%)

• Micronutrients:
  ◦ Vitamins
  ◦ Minerals (1-2.5%)

Wheat
Wheat grain

ENDOSPERM (80%)

BRAN (17%)
Incl. aleuronlayer

GERM (3%)
Wheat producing countries

(source: faostat.fao.org) Million tons (average 2005-2010)
Wheat

- Unique
  - wheat gluten proteins
  - breadmaking quality
Wheat classification

- Wheat class system depends on country

- Wheat type
  - *Triticum aestivum* (>90%)
  - *Triticum durum* (±5%)

- Criteria (USA)
  - Kernel texture: hard ↔ soft
  - Bran color: red ↔ white
  - Growth habit: spring ↔ winter
WHEAT CLASSES

- Hard Red Spring wheat
- Durum wheat
- Hard Red Winter wheat
- Soft Red Winter wheat
- Soft White Winter wheat
- Mixed wheat
Maize
Corn/Maize

- Most produced grain
- Highest yielding cereal (world average)
  - Maize: 4.3 tonnes/hectare
  - Paddy rice: 3.8 tonnes/hectare
  - Wheat: 2.7 tonnes/hectare
- Animal feed
- Human food: tortillas, porridge
- Starch production: wet milling

http://www.baobab.n
Maize grain

- **endosperm**
  - floury endosperm
  - horny endosperm
  - endosperm cells with starch granules
  - aleurone cell layer

- **bran**
  - seed coat (testa)
  - tube cells
  - cross cells
  - mesocarp
  - epidermis

- **germ (embryo)**
  - plumule
  - scutellum
  - radicle

- **tip cap**
Maize

TYPES
Dent
Soft
Waxy
Popcorn
Sweet
White
Corn producing countries

(source: faostat.fao.org)  Million tons (average 2005-2010)
Cereal milling
From cereal to flour

- Milling:
  - Separation of bran/germ from endosperm
  - Size reduction of endosperm -> flour

- Processing steps involved
  - Reception and pre-cleaning
  - Cleaning
  - Conditioning
  - Milling
  - Sieving
  - Blending
Reception

- Reception
  - intake of cereals
  - quality control!: IN -> OUT
  - different factors

- pre-cleaning
  - magnet
  - sieve cleaner
  - aspiration
Factors affecting milling yield, end use quality

- hectoliter weight
- Impurities
- Immature kernels
- Preharvest sprouting
- Insect damage

Courtesy: Marieke Dhooge

Sitophilus (weevil)
Factors affecting food safety: moulds

**FUSARIUM SPP.**

Mycotoxins!

**ERGOT**

- *Claviceps purpurea*
- Toxic alkaloids
- Difficult to separate
- 0.05% limit

Courtesy: Ingrid De Leyn

Courtesy: Kris Audenaert
Wheat grain quality control

- Fast analysis before grain intake:
  - Moisture content
  - Protein content
  - Hectoliter weight
  - % Impurities
  - Amylase activity -> Hagberg falling number
  - Gluten quality -> sedimentation value of Zeleny
Storage

- **Storage**
  - possible: low moisture content
  - BUT living substance which can decay

- **Control**
  - temperature
  - grain condition
  - oxygen supply
  - moisture content grain
    - safe value ~ cereal (13-15%)
    - drying if necessary
  - pest and mould control
Blending and cleaning

**Blending**
- wheat mix of uniform quality
- directly in storage bin
- just before milling process (other tempering conditions)

**Cleaning**
- remove impurities
  - undesired seeds, infested kernels, shrunken and broken kernels, other foreign material
- prevent contamination of mill products + damage of equipment
- separation based on differences in size, shape, specific gravity, behaviour in air currents, magnetic properties
Cleaning

SIEVE SEPARATOR

OVERSIZE
GOOD
UNDERSIZE
AIR/LIGHT PRODUCT MIX

DISC SEPARATOR

ASPIRATOR

SCOURER

MAGNET
Conditioning

Conditioning = adjustment of moisture content

- **Not too dry**
  - bran should become elastic to avoid splintering and contamination of flour
  - better separation of endosperm-bran
  - less power required to grind to flour

- **Not too wet**
  - Endosperm too soft, no creation of sharp particles
  - No efficient sieving
Conditioning

- **Tempering**
  - controlled addition of water (and heat)
  - intensive mixing to ensure uniform distribution
  - resting for a period of time (3-36 h)
    - optimal distribution in different parts of kernel
    - reduce hydration differences
  - 25°C, 15-20% moisture content
    - Soft wheat: 15 – 16.5%
    - Hard wheat: 17 - 18%
Milling: goals

- remove bran and germ
- flour with specific particle size distribution
- extract as much white flour as possible
Milling

- Milling process
  - multi-stage process
  - size reduction, separation (sieving) and purification operations
  - different materials at different stages BUT no fraction completely pure

- Milling efficiency
  - flour extraction degree
  - pureness of the fractions
Milling process

Succession of 3 systems:

- **breaking**
  - breaks up grain in large pieces
  - removing endosperm from bran
  - as little flour and bran powder as possible

- **coarse reduction (scratching or sizing)**
  - removing small pieces of bran and embryo from endosperm
  - smaller particles endosperm

- **fine reduction**
  - grinding endosperm into flour
  - minimum in crushed germ and bran powder
  - **optimum** in damaged starch granules
Roller milling
Roller milling: break system

- 4-5 breaks, corrugated rolls
  - first break opens kernel
  - subsequent breaks: scraping endosperm from the bran
  - gradually smaller but more corrugations
  - differential from 2.5 to 1
Roller milling: reduction system

- Gradual decrease of particle size into flour
- Roller mill with smooth rolls,
  - differential 1.25 to 1
  - high shear pressure, lower shear forces
- Coarse reduction: 3-5 stages
  - Removing small pieces of bran and embryo from endosperm
  - Smaller particles endosperm
  - No severe grinding: no bran in flour
- Fine reduction: 6-10 stages
  - Grinding endosperm into flour
  - Minimum in crushed germ and bran powder
  - Optimum in damaged starch granules
- Material to purifiers, final reduction, flour
Hammer mill

- impact milling
- screen determines the particle size
- requires dehulling when applied for ‘white’ flour/meal
Sieving

Plansifter

Purifier
Sieving: plansifter

- Sieving stage follows each set of rolls
  - different mill fractions
  - directed to:
    - Next break rolls
    - Reduction rolls
    - Purifier
    - Finished product
Sieving

- **Purifiers**

  - separation of pure endosperm and endosperm with different amounts of bran
  - **vibrating motion** of sieves: heavier endosperm close to sieve, brannier material on top
  - **air currents** fluidise and stratify according to size, specific gravity and shape
Four main groups of machines are shown:

- ☐ Break and reduction rolls
- 🗼 Purifiers
- ♂ Coarse
- ♂ Medium coarse
- ♂ Fine sieves

The flour streams are not shown but each representation of a bolting silk implies that a flour stream originates there and is named after the rolls that feed the sifter in question.
Milling: end products

Wheat flour

Maize meal
Milling and flour/meal quality

- Particle size
- Bran content -> ash content
- Color
- Starch damage
% Extraction

0 10 20 30 40 50 60 70 80 90 100

Whole Wheat Meal of Flour

Straight Grade Flour  Shorts and Bran

Patent Flour  Low Grade Flours

Source: principles of cereal science and technology, Hoseney
## Composition of Maize Product

<table>
<thead>
<tr>
<th>Class of Maize Product</th>
<th>Fat Content by Mass (%)</th>
<th>Fiber Content by Mass (%)</th>
<th>Fineness by Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
<td>Minimum</td>
</tr>
<tr>
<td>1. Super Maize Meal</td>
<td>-</td>
<td>Less than 2.0</td>
<td>-</td>
</tr>
<tr>
<td>2. Special Maize Meal</td>
<td>2.0</td>
<td>Less than 3.0</td>
<td>-</td>
</tr>
<tr>
<td>3. Sifted Maize Meal</td>
<td>3.0</td>
<td>Less than 4.0</td>
<td>-</td>
</tr>
<tr>
<td>4. Unsifted Maize Meal</td>
<td>3.5</td>
<td>Less than 4.5</td>
<td>More than 1.2</td>
</tr>
<tr>
<td>5. Samp</td>
<td>-</td>
<td>1.5</td>
<td>-</td>
</tr>
<tr>
<td>6. Maize Rice</td>
<td>-</td>
<td>1.5</td>
<td>-</td>
</tr>
<tr>
<td>7. Maize Grit</td>
<td>-</td>
<td>1.5</td>
<td>-</td>
</tr>
<tr>
<td>8. Maize Flour</td>
<td>-</td>
<td>Less than 2.0</td>
<td>-</td>
</tr>
<tr>
<td>9. No. 1 Straightrun Maize Meal</td>
<td>3.7</td>
<td>-</td>
<td>1.8</td>
</tr>
<tr>
<td>10. No. 2 Straightrun</td>
<td>3.7</td>
<td>-</td>
<td>More</td>
</tr>
</tbody>
</table>

Courtesy: Philip Randall
Table 1
Chemical composition (dry basis) of wheat flour in function of the extraction rate (Pederson et al., 1989)

<table>
<thead>
<tr>
<th>Component</th>
<th>Extraction rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Starch + sugar (%)</td>
<td>69.9</td>
</tr>
<tr>
<td>Protein (n × 6.25) (%)</td>
<td>14.2</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>2.7</td>
</tr>
<tr>
<td>Dietary fiber (%)</td>
<td>12.1</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>1.8</td>
</tr>
<tr>
<td>Energy (kJ/g)</td>
<td>18.5</td>
</tr>
<tr>
<td>Phosphorus (mg/g)</td>
<td>3.8</td>
</tr>
<tr>
<td>Calcium (mg/g)</td>
<td>0.44</td>
</tr>
<tr>
<td>Zinc (ppm)</td>
<td>29</td>
</tr>
<tr>
<td>Copper (ppm)</td>
<td>4.0</td>
</tr>
<tr>
<td>Iron (ppm)</td>
<td>35</td>
</tr>
<tr>
<td>Thiamine (µg/g)</td>
<td>5.8</td>
</tr>
<tr>
<td>Riboflavin (µg/g)</td>
<td>0.95</td>
</tr>
<tr>
<td>Niacin (µg/g)</td>
<td>25.2</td>
</tr>
<tr>
<td>Pyridoxine (µg/g)</td>
<td>7.5</td>
</tr>
<tr>
<td>Biotin (µg/g)</td>
<td>116</td>
</tr>
<tr>
<td>Folic acid (µg/g)</td>
<td>0.57</td>
</tr>
</tbody>
</table>
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