THE IMPACT OF THE SIZE DISTRIBUTIONS OF THE NATIVE WHEAT POWDERS ON THEIR STRUCTURATION BEHAVIOR DURING WET AGGLOMERATION

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UMR IATE – INRA Montpellier – France

8th International Granulation Workshop

Sheffield (U.K.) - 28th June 2017
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2 NATIVE WHEAT POWDERS AND METHODS
3 RESULTS - IMPACT OF DIAMETER AND SPAN
4 DISCUSSION - AGGLOMERATION MECHANISMS
5 CONCLUSION
INTRODUCTION - WET AGGLOMERATION

NATIVE WHEAT POWDERS AND METHODS

RESULTS - IMPACT OF DIAMETER AND SPAN

DISCUSSION - AGGLOMERATION MECHANISMS

CONCLUSION
Agglomeration is largely used to improve the powders properties and behaviour:

- Reduction in dust production.
- Enhancement in flowability.
- Increase in bulk density.
- Reduction in segregation.

During the agglomeration process... ...the native small particles are gathered to form larger assemblies with specific porous structures, called the agglomerates.

Agglomerated food powders
- Cocoa beverage powders
- Instant soluble coffee
- Culinary powders
- Flavors powders
- Protein powders
- Infant formulas
- Couscous grains
- Dairy powders
- Milk powders
- Bakery mixes
- Starch
Agglomeration is largely used to improve the powders properties and behaviour:
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- Enhancement in flowability.
- Increase in bulk density.
- Reduction in segregation.

During the agglomeration process... ...the native small particles are gathered to form larger assemblies with specific porous structures, called the agglomerates.
Couscous grains are made by the succession of 3 unit operations. The polydispersity of the size causes the high ratio of out of scope (up to 60%) of wet agglomerates.

Agglomeration is a key unit operation in the couscous production.
1.2. WET AGGLOMERATION - MECHANISMS

Wet agglomeration process is classically described as a combination of successive mechanisms at different rates:

- Wetting and nucleation.
- Growth and consolidation.
- Breakage, erosion, rupture.

The cohesion forces generate interactions between particles, and promote granules growth.

**Diagram:**
- **Wetting**
- **Nucleation**
- **Growth**
- **Consolidation**

**Native powder**

**Agglomerates**
1.2. WET AGGLOMERATION - MECHANISMS

Wet agglomeration process is classically described as a combination of successive mechanisms at different rates:

- Wetting and nucleation.
- Growth and consolidation.
- Breakage, erosion, rupture

The rupture forces and shearing effects, lead to breakage and to reduce the granule size.

The wet agglomeration process is a balance between growth and breakage.
INTRODUCTION

1.2. WET AGGLOMERATION - MECHANISMS

During the agglomeration process, a liquid binder (water) is sprayed over an agitated powder bed.

It generates attractive interactions and links between the native particles and...

... Promotes the spatial arrangement of the native particles with the binder.

The native particle characteristics, like the particle size, control the agglomeration mechanisms and the end properties of the products.

http://www.cjtech.co.kr/Process%20Principles%20Agglomeration%20Granulation.htm
Hydrotextural approach is used to describe agglomeration mechanisms based on changes in compactness and diameter of the agglomerates as a function to the water content.

Hydrotextural diagram is limited by the saturation curve until which agglomerates are completely filled by water.

Agglomerates were analysed by measuring:

- **Size** = Median diameter
- **Water content** = Mass of water / Mass of dry product
- **Compactness** = Volume of solid / Total Volume
- **Saturation degree** = Volume of liquid / Volume of void

Schema of the hydrotextural diagram (Ruiz et al., 2005)
1.4. OBJECTIVES

No study on the impact of the particle size of native semolina during the agglomeration in the process of the couscous grain has been conducted yet.

INTRODUCTION

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1.4. OBJECTIVES

No study on the impact of the particle size of native semolina during the agglomeration in the process of the couscous grain has been conducted yet.

OUR OBJECTIVES WERE:

➔ To describe the agglomeration operation of the couscous grains by analysing experimental investigations.

➔ To understand how the particle size distribution of semolina impact the agglomeration operation of the couscous grains.
THE IMPACTS OF THE SIZE DISTRIBUTIONS OF THE NATIVE WHEAT POWDERS ON THEIR STRUCTURATION BEHAVIOR DURING WET AGGLOMERATION
2.1. NATIVE WHEAT POWDERS

Durum wheat semolina of industrial quality was used as “standard semolina”.

4 fractions of semolina with different particle size distributions were obtained by sieving the standard semolina.
2.1. NATIVE WHEAT POWDERS

The selected semolina allow studying the effect of particle size distributions: $d_{50}$ and span, with almost similar values of the physico-chemical properties.

<table>
<thead>
<tr>
<th></th>
<th>Standard</th>
<th>Small</th>
<th>Low span</th>
<th>Coarse</th>
<th>Very coarse</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_{50}$ (µm)</td>
<td>287</td>
<td>129</td>
<td>282</td>
<td>339</td>
<td>393</td>
<td>Laser granulometry</td>
</tr>
<tr>
<td>Particle size span (-)</td>
<td>1.51</td>
<td>1.58</td>
<td>0.92</td>
<td>1.02</td>
<td>0.77</td>
<td>Laser granulometry</td>
</tr>
<tr>
<td>Water content (%)</td>
<td>17.30</td>
<td>15.70</td>
<td>16.00</td>
<td>13.90</td>
<td>16.10</td>
<td>Method 44-15A AACC</td>
</tr>
<tr>
<td>Protein content(%)</td>
<td>12.4</td>
<td>13.02</td>
<td>12.66</td>
<td>12.39</td>
<td>12.35</td>
<td>Method 050 (AFNOR</td>
</tr>
<tr>
<td>True density $\rho_s^*$ (g/cm³)</td>
<td>1.42</td>
<td>1.46</td>
<td>1.45</td>
<td>1.45</td>
<td>1.45</td>
<td>Helium pycnometry</td>
</tr>
</tbody>
</table>
2.2. DIRECT WET AGGLOMERATION PROCESSES

**MATERIALS & METHODS**

**THE IMPACTS OF THE SIZE DISTRIBUTIONS OF THE NATIVE WHEAT POWDERS ON THEIR STRUCTURATION BEHAVIOR DURING WET AGGLOMERATION**

**Horizontal mixer**
- Low shear conditions
- Two horizontal shaft axes
- Laboratory scale
- Constant mixing rate (100 rpm-15min)

**Single fluid nozzle**
- $d_g = 240 \mu m \rightarrow$ Change in the ratio $d_{50}/d_g$
- Flow rate = 2 g.sec$^{-1}$
- Final water content = 0.45 g/g dry matter
- Constant final mass = 1000 g (semolina + water)
2.3. AGGLOMERATES CHARACTERISTICS

To describe the agglomeration mechanisms and the product characteristics, we evaluated the size distribution and the agglomerates characteristics on each sieve.

**Size distribution** by sieving: $d_{50}$, span, yield per sieves

**Distribution of water content** by weighing after oven drying at 105°C for 24h

**Distribution of compactness** hydrostatic balance (Precisa serie 321 LX 120+ density kit)
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Large dispersion in size was observed. Specific shape and hydrotectural characteristics allow distinguishing 5 types of structures according to their diameter:

- **Small** (0.3 – 0.5 mm) = native particles of semolina
- **Fragments** (0.5 – 0.6 mm) = mechanical erosion of larger structures
- **Nuclei** (0.6 – 1.0 mm) = primary association of semolina particles
- **Agglomerates** (1.0 – 2.0 mm) = association of fragments and/or nuclei
- **Dough pieces** (>2.0 mm) = association of agglomerates which passes the percolation state
3.1. AGGLOMERATION OF STANDARD SEMOLINA

Agglomeration growth of semolina to produce couscous grains leads to:

- Increasing water content
- Decreasing compactness

according to an increase in the median diameter of the structures.

Evolution of the size distribution of the agglomerated structures with compactness shows a continuous growth process associated with the expansion of their internal structure.

Mechanisms deal with (i) a classical growth and (ii) a fragmentation of dough pieces.
3.2. IMPACT OF THE DIAMETER

5 types of structures are presents in the mixer after the agglomeration. Ratio of each structure is different with a change in the $d_{50}$ of the size distributions of semolina.

The median diameter of the native semolina strongly impact the agglomeration yield.
3.2. IMPACT OF THE DIAMETER

An increase of the d50 of the semolina leads to:

→ increasing the dough pieces, the small and the fragments.

<table>
<thead>
<tr>
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<th>d50 (µm)</th>
<th>Small (%)</th>
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<th>Dough pieces (%)</th>
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<tr>
<td>Low span semolina</td>
<td>282</td>
<td>3.7</td>
<td>1.7</td>
<td>41.0</td>
<td>27.6</td>
<td>17.0</td>
</tr>
<tr>
<td>Coarse semolina</td>
<td>339</td>
<td>13.9</td>
<td>12.6</td>
<td>12.2</td>
<td>27.9</td>
<td>22.1</td>
</tr>
<tr>
<td>Very coarse semolina</td>
<td>393</td>
<td>28.0</td>
<td>18.1</td>
<td>7.4</td>
<td>18.8</td>
<td>20.6</td>
</tr>
</tbody>
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3.2. IMPACT OF THE DIAMETER

An increase of the d50 of the semolina leads to:
→ increasing the dough pieces, the small and the fragments.
→ decreasing the nuclei and the agglomerates.

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<th></th>
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3.3. IMPACT OF THE SPAN

5 types of structures are presents in the mixer after the agglomeration. Ratio of each structure is different with a change in the span of the size distribution of semolina.

The span of the native semolina strongly impact the agglomeration yield.
3.3. IMPACT OF THE SPAN

An increase of the span of the semolina leads to:

→ increasing the small and the fragments.

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<tr>
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<td>3.7</td>
<td>1.7</td>
<td>41.0</td>
<td>27.6</td>
</tr>
<tr>
<td>Standard semolina</td>
<td>1.51</td>
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<td>12.5</td>
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<td>27.2</td>
</tr>
</tbody>
</table>
3.3. IMPACT OF THE SPAN

An increase of the span of the semolina leads to:

→ increasing the small and the fragments.
→ decreasing the nuclei.

|                  | Span  | Small (%) | Fragments (%) | Nuclei (%) | Agglomerates (%) | Dough pieces (%) |
|------------------|-------|-----------|               |            |                 |                 |
| Low span semolina| 0.92  | 3.7       | 1.7           | 41.0       | 27.6             | 17.0             |
| Standard semolina| 1.51  | 22.7      | 12.5          | 10.9       | 27.2             | 19.3             |
Same trends were observed concerning the evolution of water content and compactness according to the diameter of the structure...

...The median diameter and the span do not impact the compactness and the water content of each structure according to their median diameters.
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4.1. HYDROTEXTURAL ANALYSIS

We have represented on the diagram the values of water content and compactness of the different structures for the standard semolina.

The structures on each sieve follow the saturation curve.
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The structures on each sieve follow the saturation curve.
4.1. HYDROTEXTURAL ANALYSIS

We have represented on the diagram the mean values of water content and compactness of the structures for all the different size distributions of semolina.

The size distributions of semolina do not change the hydrotextrual properties of the structure: they are all saturated by water.
4.1. HYDROTEXTURAL ANALYSIS

**Fluctuations** of the water content and the compactness are **correlated** around their respective mean values for all the different size distributions of semolina.

The growth of the agglomerates respects an **association by the same hydro-textural categories**.
4.2. AGGLOMERATION MECHANISMS

Agglomeration mechanisms was studied regarding the ratio of the median diameter of the semolina particles on the median diameter of the droplets of water ($d_{50}/d_g$):

$d_{50}/d_g \leq 1$

- **Nuclation/growth**
  - Small
  - Nuclei
  - Agglomerates
  - Dough pieces

- **Paste/fragmentation**
  - Fragments

$d_{50}/d_g \leq 1$ or lower span $\Rightarrow$ Mechanism of **nucleation/growth** is favoured.
4.2. AGGLOMERATION MECHANISMS

Agglomeration mechanisms was studied regarding the ratio of the median diameter of the semolina particles on the median diameter of the droplets of water ($d_{50}/d_g$):

$$d_{50}/d_g \geq 1$$

**Nuclation/growth**

**Paste/fragmentation**

$d_{50}/d_g \geq 1$ or higher span $\rightarrow$ Mechanism of paste/fragmentation is favoured.
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CONCLUSION

• The size distributions ($d_{50}$ and span) of the semolina particles has a significant influence on the yield of the agglomeration.

• Continuous growth process is associated with the expansion of the internal structure.

• These mechanisms deal with:
  (i) Classical growth of associated particles to nuclei, then nuclei to agglomerates, and percolation to local paste state (dough pieces)
  (ii) Fragmentation of dough pieces into a specific population of small saturated clusters, which are able to interact with nuclei.

• As a function to the ratio of $d_{50}/d_g$ one major mode is favoured:
  $d_{50}/d_g \leq 1$ the nucleation/growing is favoured.
  $d_{50}/d_g \geq 1$ the paste/fragmentation is favoured.
Thank you for your attention!

QUESTIONS?

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