



## **Agglomeration process engineering approach to evaluate the ability of different technologies to agglomerate food powder.**

Ines Hafsa, Sandra Mandato, Charleyne Lafond, Serge Mejean, Anne Dolivet, Pierre Schuck, Romain Jeantet, S. Jin Kim, S. Chevallier, A. Le Bail, et al.

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**5th IDF / INRA International Symposium on Spray Dried Dairy Products**  
*St-Malo – France, 19 – 21 June 2012*

**Agglomeration process engineering approach to  
evaluate the ability of different technologies to  
agglomerate food powder**

**HAFSA Ines** <sup>(1)</sup>, **MANDATO Sandra** <sup>(1)</sup>, **LAFOND Charline** <sup>(1)</sup>  
**MEJEAN Serge** <sup>(2)</sup>, **SCHUCK Pierre** <sup>(2)</sup>, **JEANTET Romain** <sup>(2)</sup>, **KIM Su Jin** <sup>(3)</sup>, **CHEVALLIER Sylvie** <sup>(3)</sup>  
**LE BAIL Alain** <sup>(3)</sup>, **RUIZ Thierry** <sup>(1)</sup>, and **CUQ Bernard** <sup>(1)</sup>

(1) UMR IATE, Montpellier.

(2) UMR STLO, Rennes.

(3) UMR GEPEA, Nantes.



# Summary



## 1. Product context

- Food powders
- Food powders **agglomeration**

## 2. Scientific contexts

- Grains elaboration - Growth and drying
- Elaboration **mechanisms**
- Reactive food powders

## 3. Materials and Methods

- Raw materials
- Agglomeration **processes**
- Product characterization

## 4. Results

- Agglomeration yields
- Agglomerates **characterization**

## 5. Conclusion



## Context - Food Powders

### Food powders



Granulated sugar



Table salt



Cocoa



Wheat flour

### Food powders

- **Natural** powders (*flours, salt, etc.*)
- **Transformed** and formulated powders (*instant coffee, dried milk*)

### Powders functionalities

- **Structuring** (*thickness, gelling agent, etc.*)
- **Organoleptic qualities** (*flavours, colouring agent, additives, etc.*)
- **Nutritional composition** (*vitamins, minerals, etc.*)



# Context - Food Powders Agglomeration

## Agglomerated food powders



Couscous grains



Instant coffee



Food flavours



Infant formula

## Agglomeration

Process where fine particles are bound together into larger granules

## Processes

- Spray drying
- Fluidized bed
- Low shear mixer
- High shear mixer

## Objectives

- Dust free powders
- Particle design  
(size, shape, porosity)
- Flow properties
- Solubility
- Heat and mass transfer
- etc.



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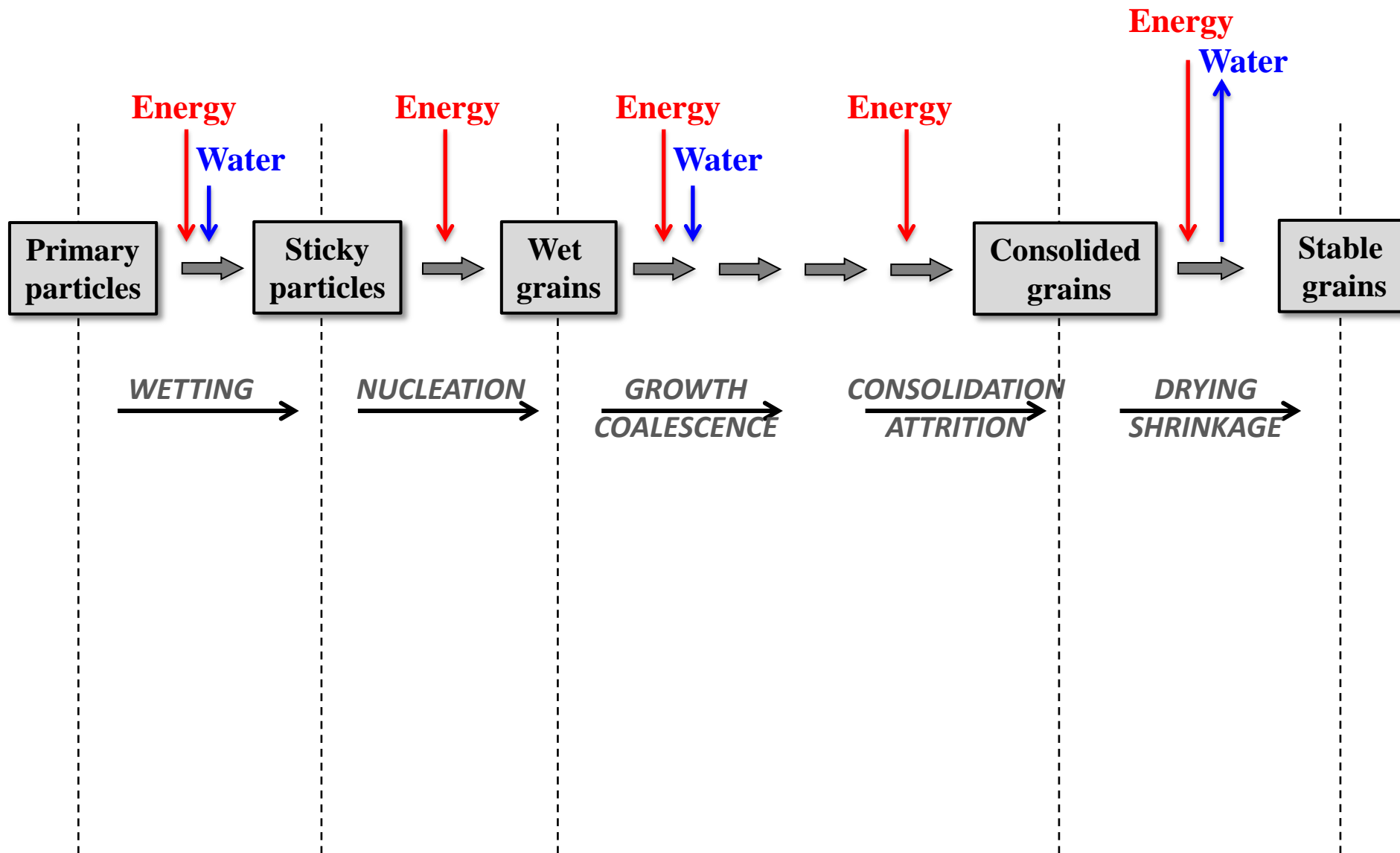
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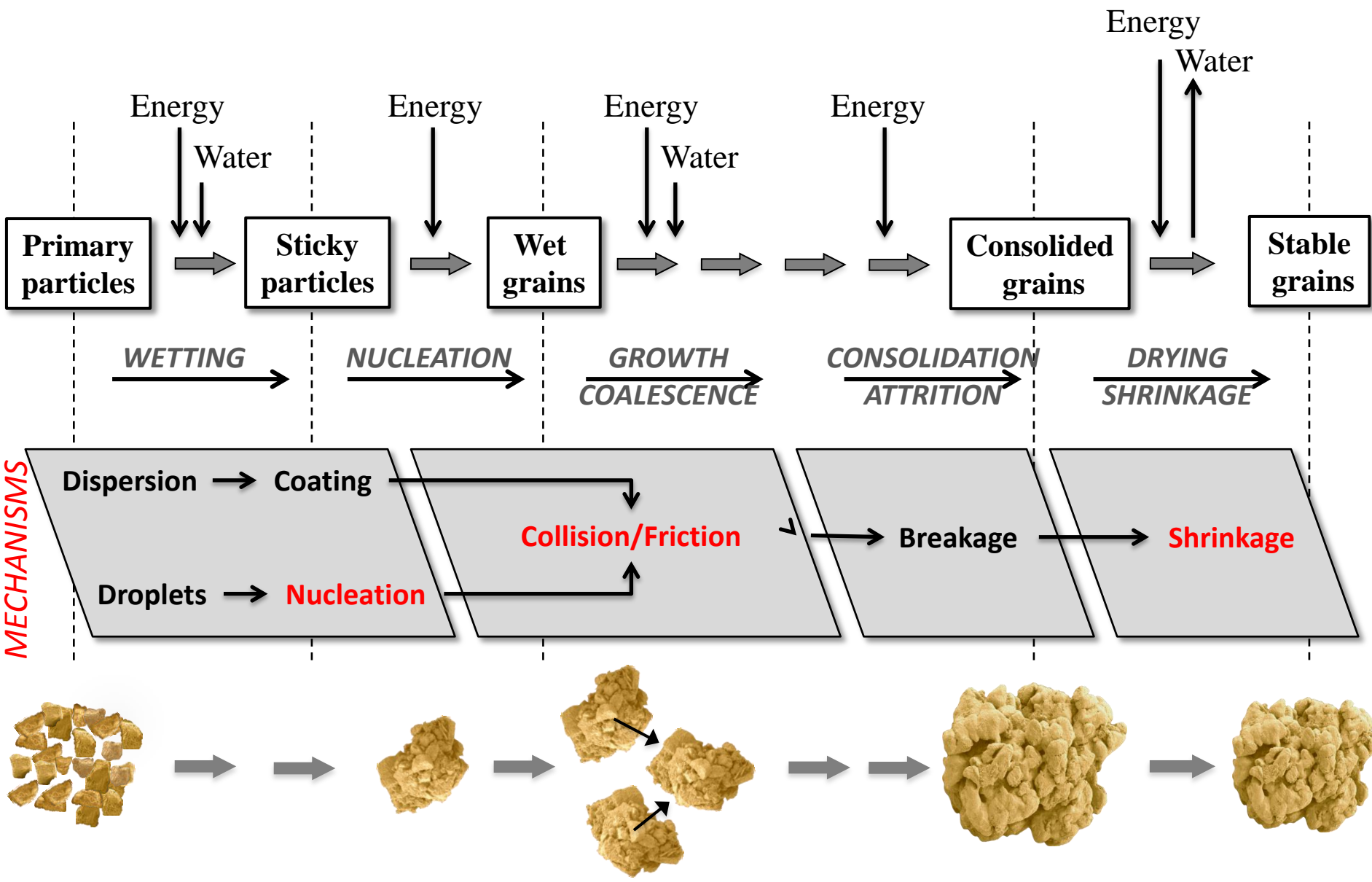
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# Grains elaboration - Growth & Drying



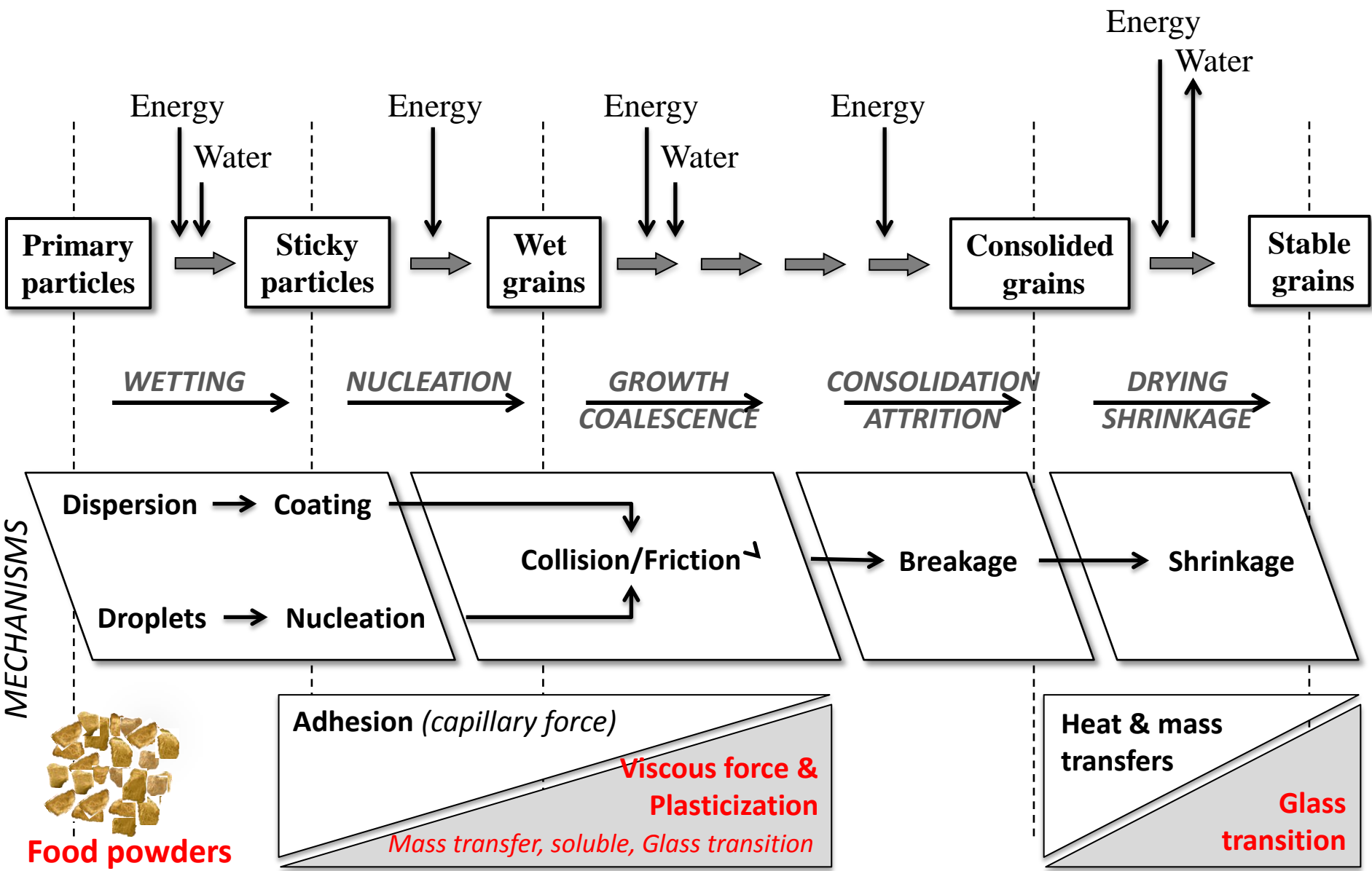


# Growth & Drying - Mechanisms



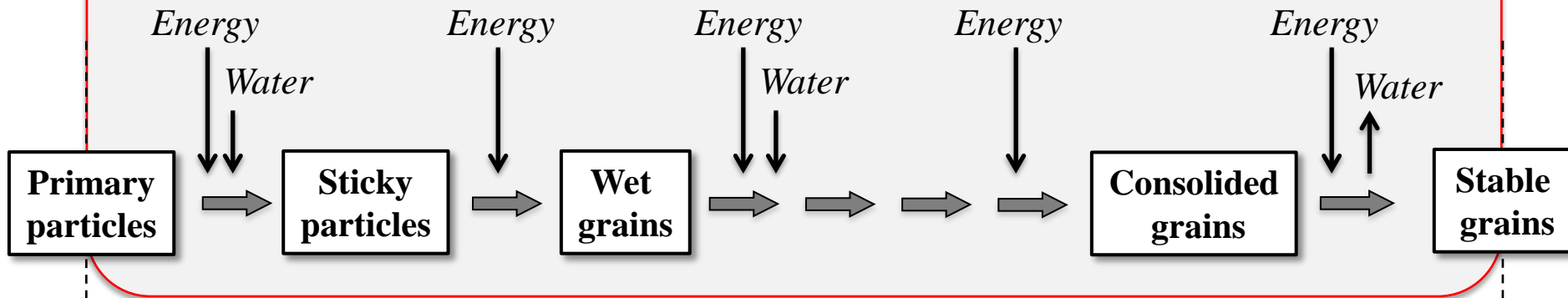


# Growth & Drying – Reactive food powders



## Coupled approach

### Pneumatal energy – Thermal energy



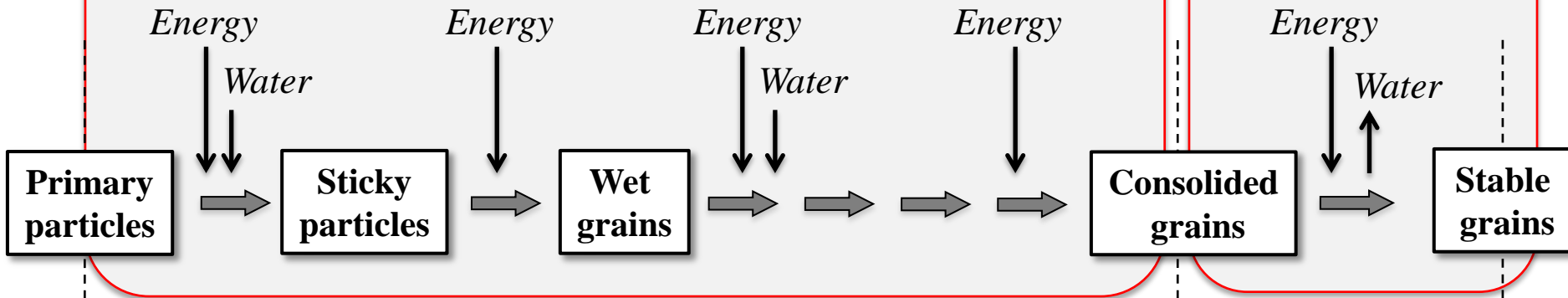
**Spray drying/ Fluidized bed** : Semolina is agglomerated when tap water is sprayed under a flow of hot air.

**[Hydration + Growth + Reaction + Drying]**

# Decoupled approach

## Mechanical energy

## Thermal energy



### Horizontal/Vertical low shear mixer :

Spraying water on the semolina and mixing using a blade

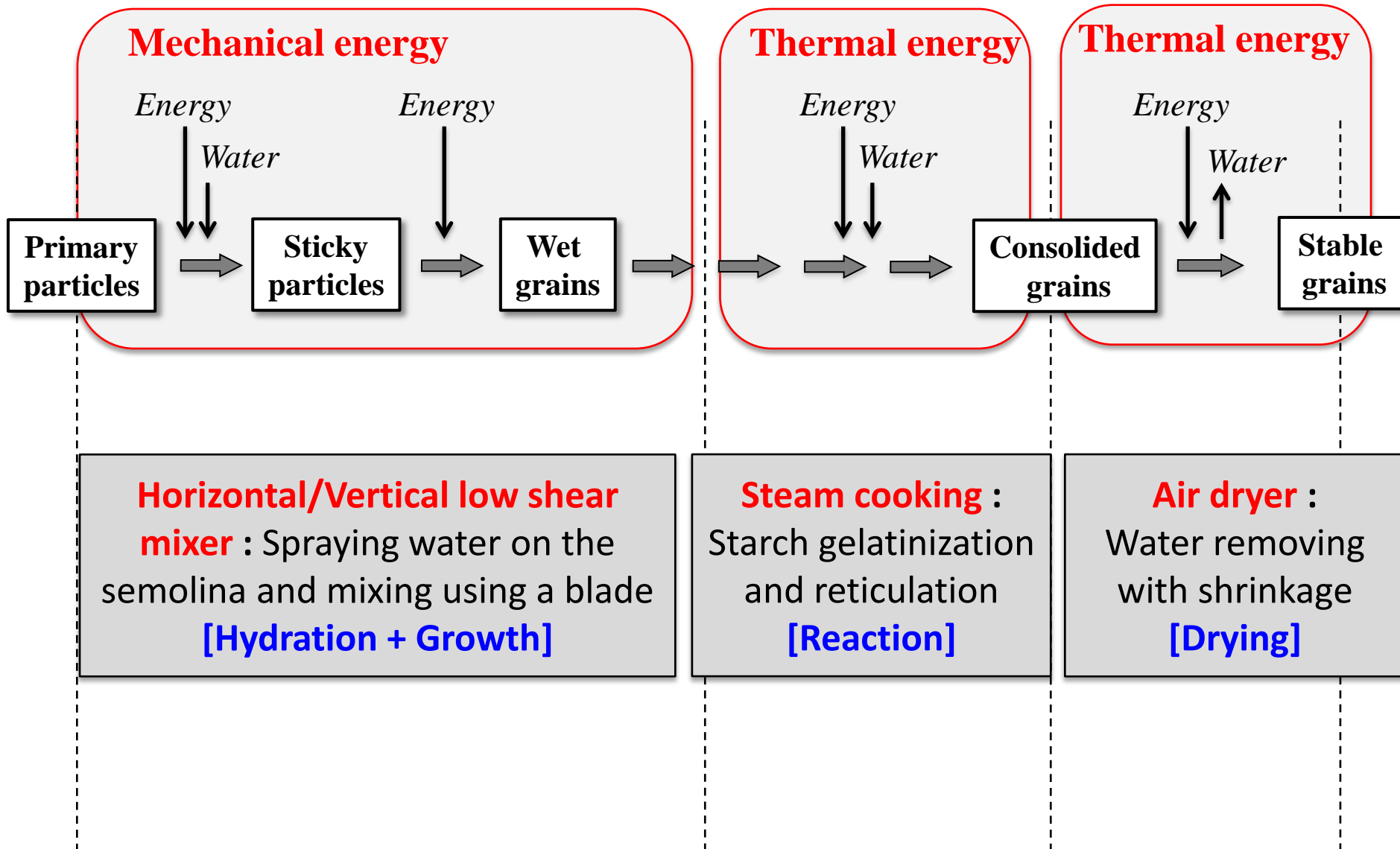
[Hydration + Growth]

### Air dryer :

Water removing with shrinkage

[Drying]

# Decoupled approach





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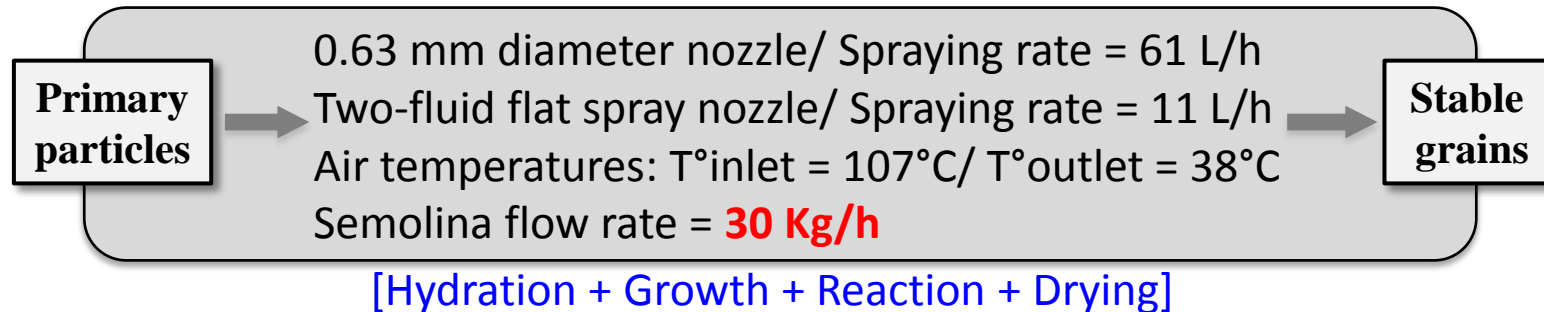
## 5. Conclusion



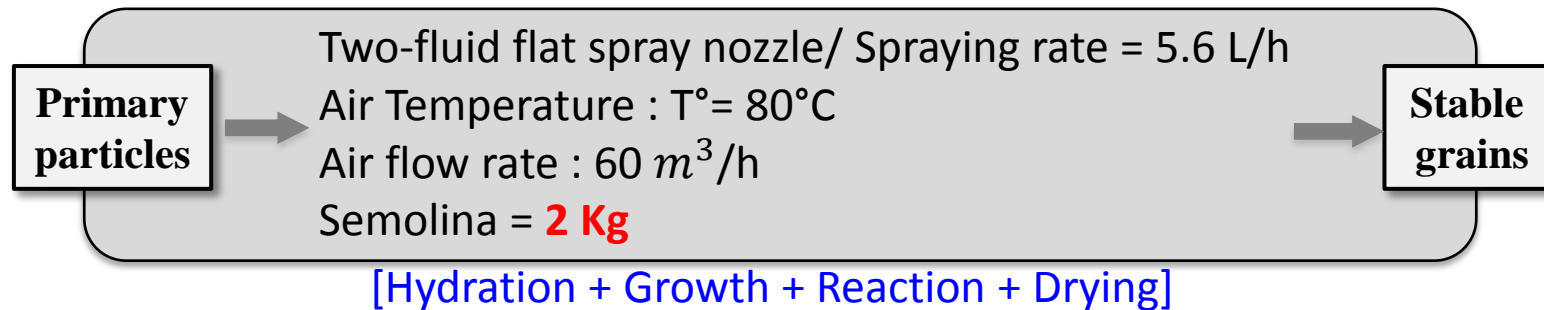
**Raw Materials** : Durum wheat semolina - Industrial couscous samples (1 & 2)

**Pneumatical energy – Thermal energy**

**Spray dryer** MSD 20, GEA- Niro (Bionov, **Rennes**)



**Fluidized bed** ProCell 5, Glatt (Bionov, **Rennes**)



## Decoupled approach

**Raw Materials** : Durum wheat semolina - Industrial couscous samples (1 & 2)

**Mechanical energy – Thermal energy**

**Horizontal mixer** *Sarcom (Supagro, Montpellier)* – **Air dryer** *Afrem (Supagro, Montpellier)*

Primary  
particles

Mono-fluid flat spray nozzle/ Hydration = 40% db  
Blade speed = 60 rpm  
Semolina = **0.8 Kg**

[Hydration + Growth]

Air temperature : T= 50°C  
Air Humidity : RH = 50%  
Time = 90min

[Drying]

Stable  
grains

**Vertical mixer** *VMI (Supagro, Montpellier)* – **Air dryer** *Afrem (Supagro, Montpellier)*

Primary  
particles

Mono-fluid flat spray nozzle/ Hydration = 40% db  
Blade speed = 80 rpm  
Bowl speed = 9 rpm  
Semolina = **1.5 Kg**

[Hydration + Growth]

Air temperature : T= 50°C  
Air Humidity : RH = 50%  
Time = 90min

[Drying]

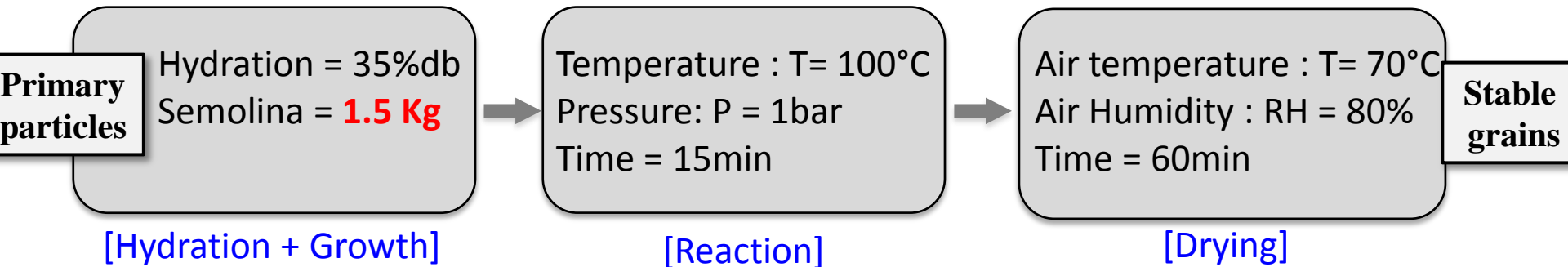
Stable  
grains

## Decoupled approach

**Raw Materials** : Durum wheat semolina - Industrial couscous samples (1 & 2)

**Mechanical energy – Steam cooking – Thermal energy**

**Vertical mixer** VMI (Supagro, **Montpellier**) – **Steam cooker** – **Air dryer** Afrem (Supagro, **Montpellier**)



## Product characterization



### **Molecular scale**

- Water content

### **Macromolecular scale**

- Starch gelatinization (DSC)

### **Microstructural scale**

- External microstructure (SEM)
- Internal microstructure (XMT)
- Compactness

### **Functional attributes**

- Swelling capacity
- Cohesion (FT4)
- Coefficient of friction (FT4)



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## Agglomeration yield

<i>Process</i>	<i>Technology</i>	<b>Agglomeration yield (%)</b>
<b><i>Coupled process</i></b>	Spray dryer	<b>15.7</b>
	Fluidized bed	<b>47.6</b>
<b><i>Decoupled process</i></b>	Horizontal mixer - dryer	<b>17.7</b>
	Vertical mixer - dryer	<b>13.7</b>
<b><i>Decoupled &amp; reaction process</i></b>	Vertical mixer - cooker - dryer	<b>12.5</b>
	Industrial 1	?
	Industrial 2	?

- **Agglomerates** were **obtained** whatever the technology used.
- **It is possible** to produce couscous grains using a spray drying chamber!!!
- **Decoupled & reaction processes** show the lowest agglomeration yield : *The reaction step (steam-cooking) has no effect on the agglomeration yield.*

## Molecular & macromolecular scales

<i>Process</i>	<i>Technology</i>	<b>Water content(%)db</b>	<b>Starch gelatinization (%)</b>
<b><i>Coupled process</i></b>	Spray dryer	10.2 (0.1) <sup>c</sup>	13.8 (1.9) <sup>b</sup>
	Fluidized bed	10.2 (0.1) <sup>c,b</sup>	<b>10.0 (0.9)<sup>a</sup></b>
<b><i>Decoupled process</i></b>	Horizontal mixer - dryer	9.3 (0.1) <sup>a</sup>	14.4 (1.3) <sup>b</sup>
	Vertical mixer - dryer	10.0 (0.1) <sup>b</sup>	14.7 (1.3) <sup>b</sup>
<b><i>Decoupled &amp; reaction process</i></b>	Vertical mixer - cooker - dryer	9.4 (0.1) <sup>a</sup>	<b>100 (0.1)<sup>c</sup></b>
	Industrial 1	10.5 (0.1) <sup>d</sup>	100 (0.1) <sup>c</sup>
	Industrial 2	10.8 (0.1) <sup>d</sup>	100 (0.1) <sup>c</sup>

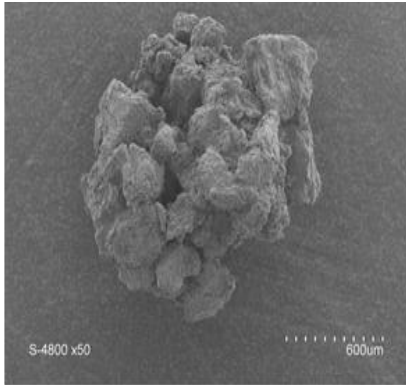
- **No differences in water contents** between the products: all the technologies used *are able to remove water*.
- **Decoupled & reaction processes** induce the highest **starch gelatinization** values : *the reaction step (steam cooking)*.

## Microstructural scale

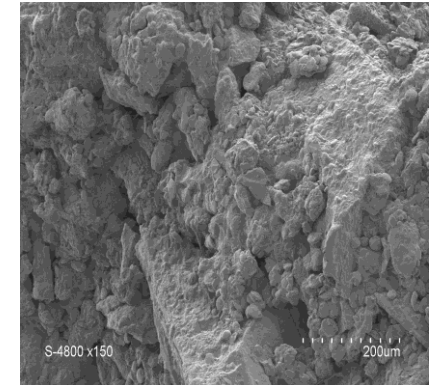
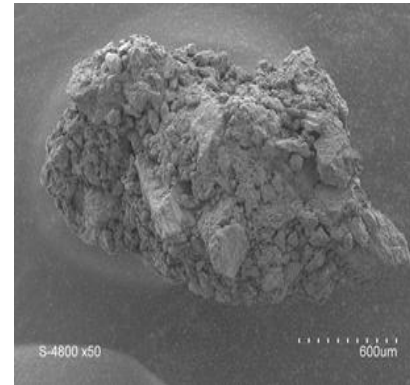
<i>Process</i>	<i>Technology</i>	<i>Compactness</i>
<b><i>Coupled process</i></b>	Spray dryer	0.856 (0.017) <sup>c</sup>
	Fluidized bed	0.810 (0.003) <sup>a</sup>
<b><i>Decoupled process</i></b>	Horizontal mixer - dryer	0.817(0.016) <sup>a,b</sup>
	Vertical mixer - dryer	<b>0.794 (0.005)<sup>a</sup></b>
<b><i>Decoupled &amp; reaction process</i></b>	Vertical mixer - cooker - dryer	<b>0.879 (0.021)<sup>c</sup></b>
	Industrial 1	0.866 (0.002) <sup>c</sup>
	Industrial 2	0.836(0.010) <sup>b,c</sup>

- **Significant** differences in **compactness** are observed.
- **Decoupled & reaction processes** induce the highest compactness values : *the reaction step (steam cooking) generates a higher microstructural changes.*

## Microstructural scale (SEM)



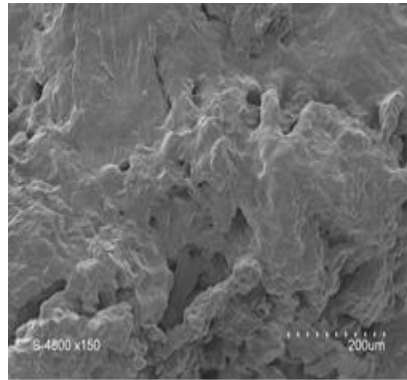
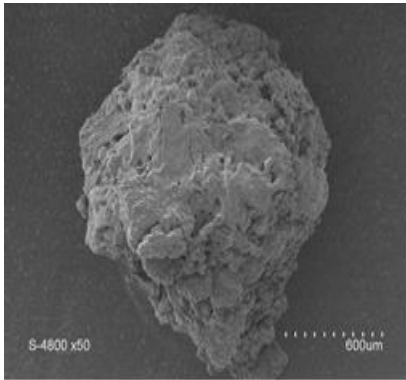
**Spray dryer**  
(magnifications X50 and X150)



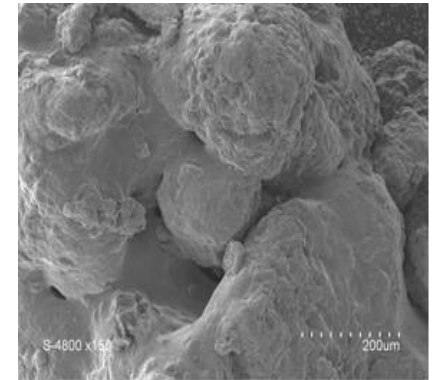
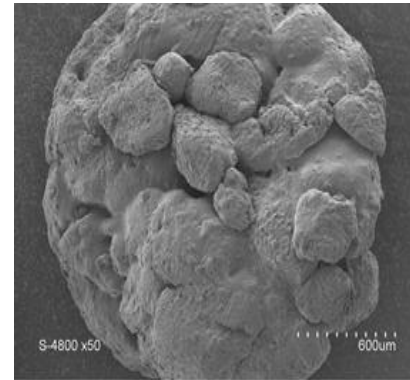
**Vertical mixer - Air dryer**  
(magnifications X50 and X150)

- **Differences** in the **shape and surface** of the grains.
- **Coupled processes** generate agglomerates formed with only large size primary particles : (*segregation effects*).
- **Decoupled processes** generate agglomerates formed with both large particles / small particles.

## Microstructural scale (SEM)



**Vertical mixer - cooker - dryer**  
*(magnifications X50 and X150)*

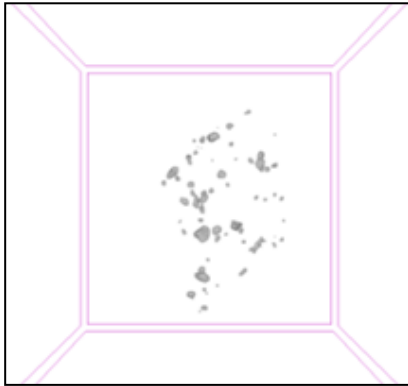
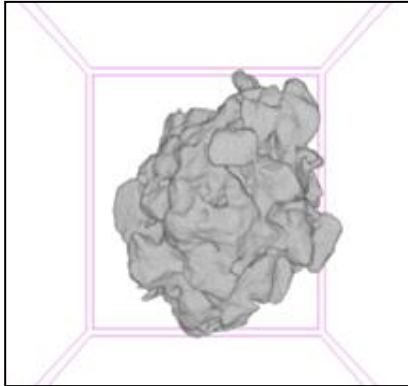


**Industrial couscous 2**  
*(magnifications X50 and X150)*

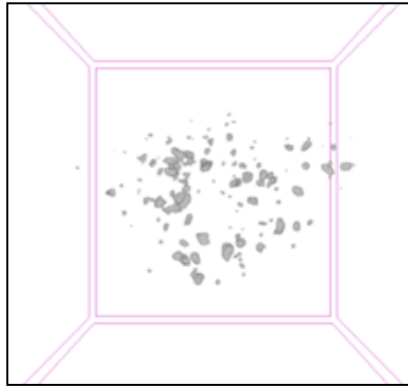
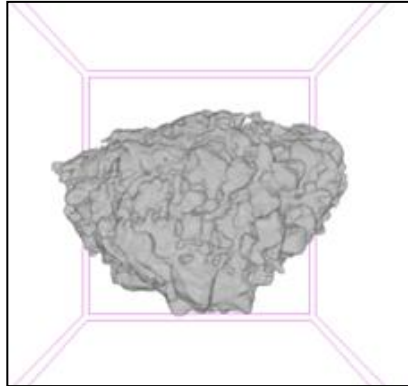
- **Decoupled & reaction processes** induce **differences in the external surface** : *the reaction step (steam cooking) induce a partly melted semolina particles at the surface with a more regular faces.*



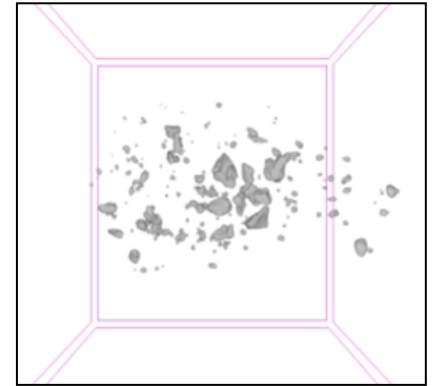
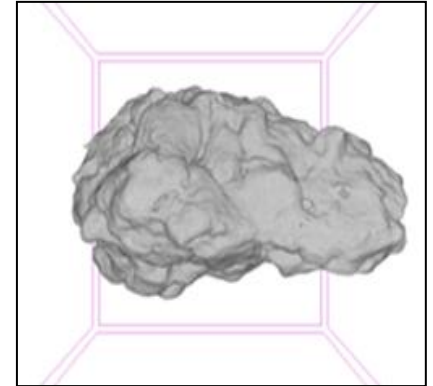
## Microstructural scale (XMT)



**Spray dryer**



**Vertical mixer - Air dryer**



**Industrial couscous 2**

- **Agglomeration processes** generate differences in voids distribution within the agglomerates.

## Functional attributes

<i>Process</i>	<i>Technology</i>	<b>Swelling capacity</b> ml moist product/100g dry product
<b><i>Coupled process</i></b>	Spray dryer	241 (1) <sup>c</sup>
	Fluidized bed	250 (0) <sup>d</sup>
<b><i>Decoupled process</i></b>	Horizontal mixer - dryer	<b>231 (1)<sup>a</sup></b>
	Vertical mixer - dryer	234 (1) <sup>b</sup>
<b><i>Decoupled &amp; reaction process</i></b>	Vertical mixer - cooker - dryer	345 (0) <sup>e</sup>
	Industrial 1	325 (0) <sup>f</sup>
	Industrial 2	<b>400 (0)<sup>g</sup></b>

- **Decoupled & reaction processes** induce the highest swelling capacity values : The reaction step (*steam cooking*) leads to higher starch gelatinization levels which enhances water absorption and swelling capacity.

## Results – Agglomerates characterization

### Functional attributes

$$\text{Coulomb Law : } \tau = \mu \sigma + C$$

<i>Process</i>	<i>Technology</i>	<i>Coefficient of friction <math>\mu</math></i>	<i>Cohesion C (kPa)</i>
<b><i>Coupled process</i></b>	Spray dryer	0.294 (0.023) <sup>a,b</sup>	0.297 (0.045) <sup>b</sup>
	Fluidized bed	0.324 (0.021) <sup>b</sup>	0.316 (0.043) <sup>b</sup>
<b><i>Decoupled process</i></b>	Horizontal mixer - dryer	0.351 (0.015) <sup>b</sup>	0.340 (0.045) <sup>b</sup>
	Vertical mixer - dryer	0.268 (0.012) <sup>a</sup>	0.266 (0.064) <sup>a,b</sup>
<b><i>Decoupled &amp; reaction process</i></b>	Vertical mixer - cooker - dryer	0.404 (0.028) <sup>c</sup>	0.333 (0.034) <sup>b</sup>
	Industrial 1	0.438 (0.006) <sup>c</sup>	0.366 (0.012) <sup>b</sup>
	Industrial 2	0.469(0.043) <sup>c</sup>	0.389 (0.119) <sup>b</sup>
<b>Semolina</b>		<b>0.600(0.005)<sup>d</sup></b>	<b>0.191 (0.046)<sup>a</sup></b>

- All the **processes** used reduce the frictional properties but slightly increase the cohesion values compared to native semolina particles.



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- All the investigated **processes** (coupled process, decoupled process, decoupled & reaction process) are **able to agglomerate** food powder to produce grains with different attributes.
- The **type and intensity of the energy** input (thermal energy, mechanical energy and pneumatical energy) affect the internal microstructure of the agglomerates (more or less compactness, differences in the voids distribution).
- The **reaction stage** (steam cooking) induces external and internal microstructure changes, because of the high gelatinization level of the starch granules.
- Semolina is a **reactive food powder** with low water solubility, different agglomeration results are expected with more soluble food powders (i.e milk powders).





Thank you for your attention

