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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

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(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

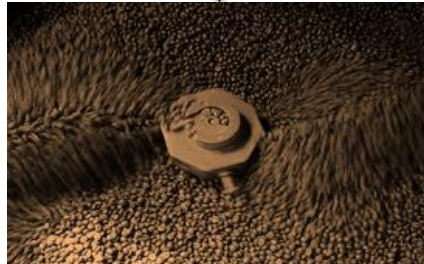
- **Structuring** (*thickness, gelling agent, etc.*)
- **Organoleptic qualities** (*flavours, colouring agent, additives, etc.*)
- **Nutritional composition** (*vitamins, minerals, etc.*)

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.



Summary



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- *Agglomeration processes*
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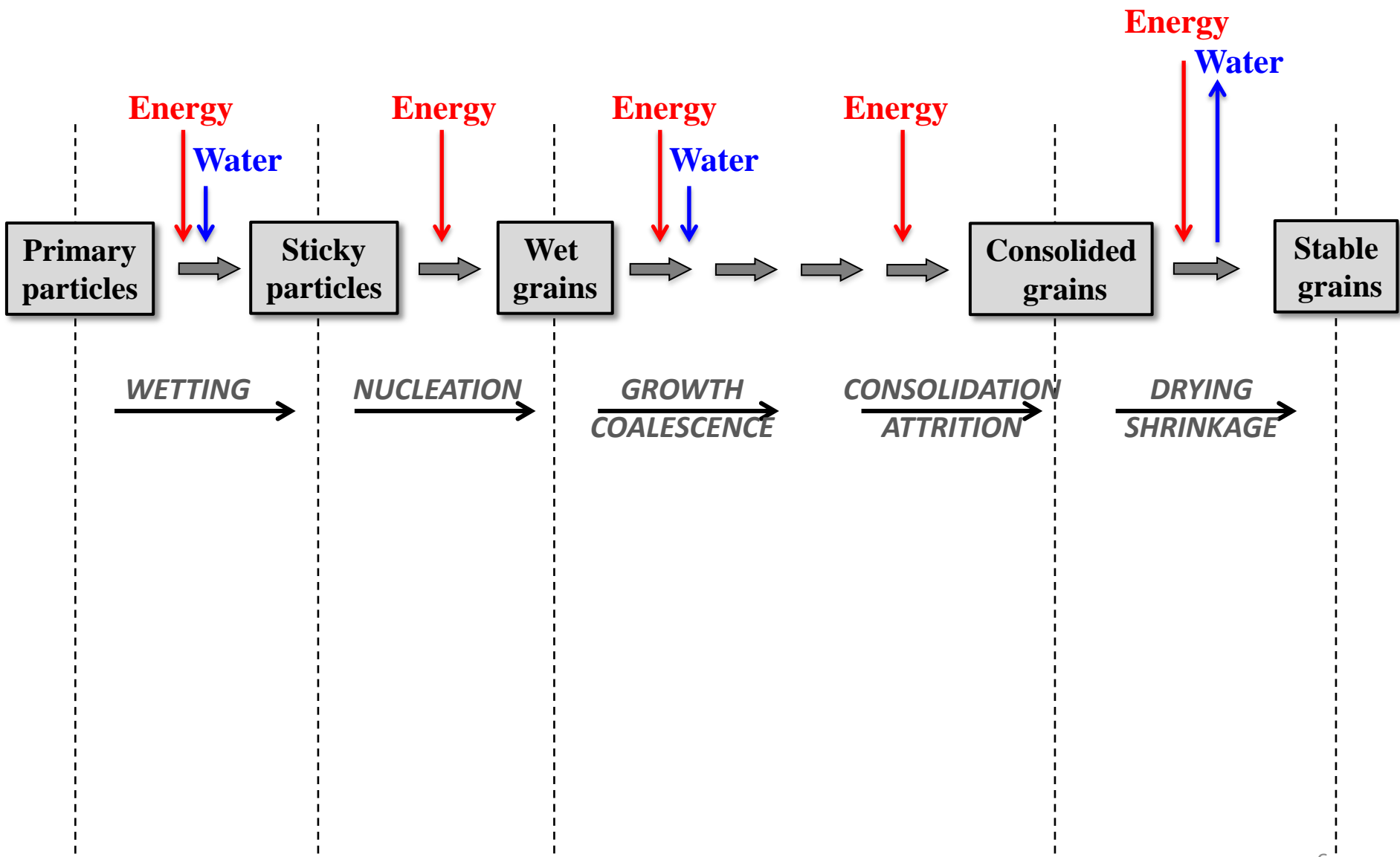
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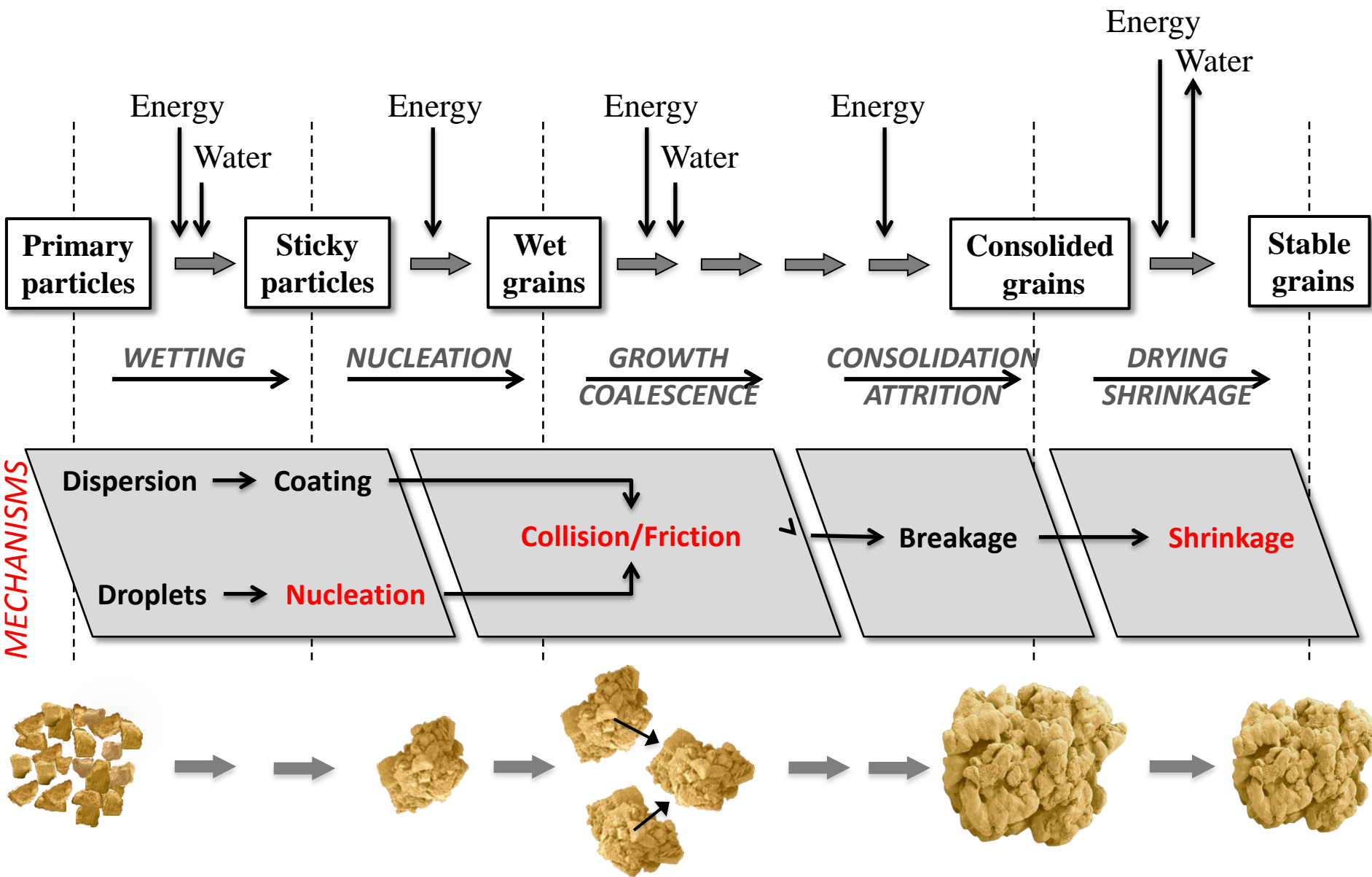


Grains elaboration - Growth & Drying

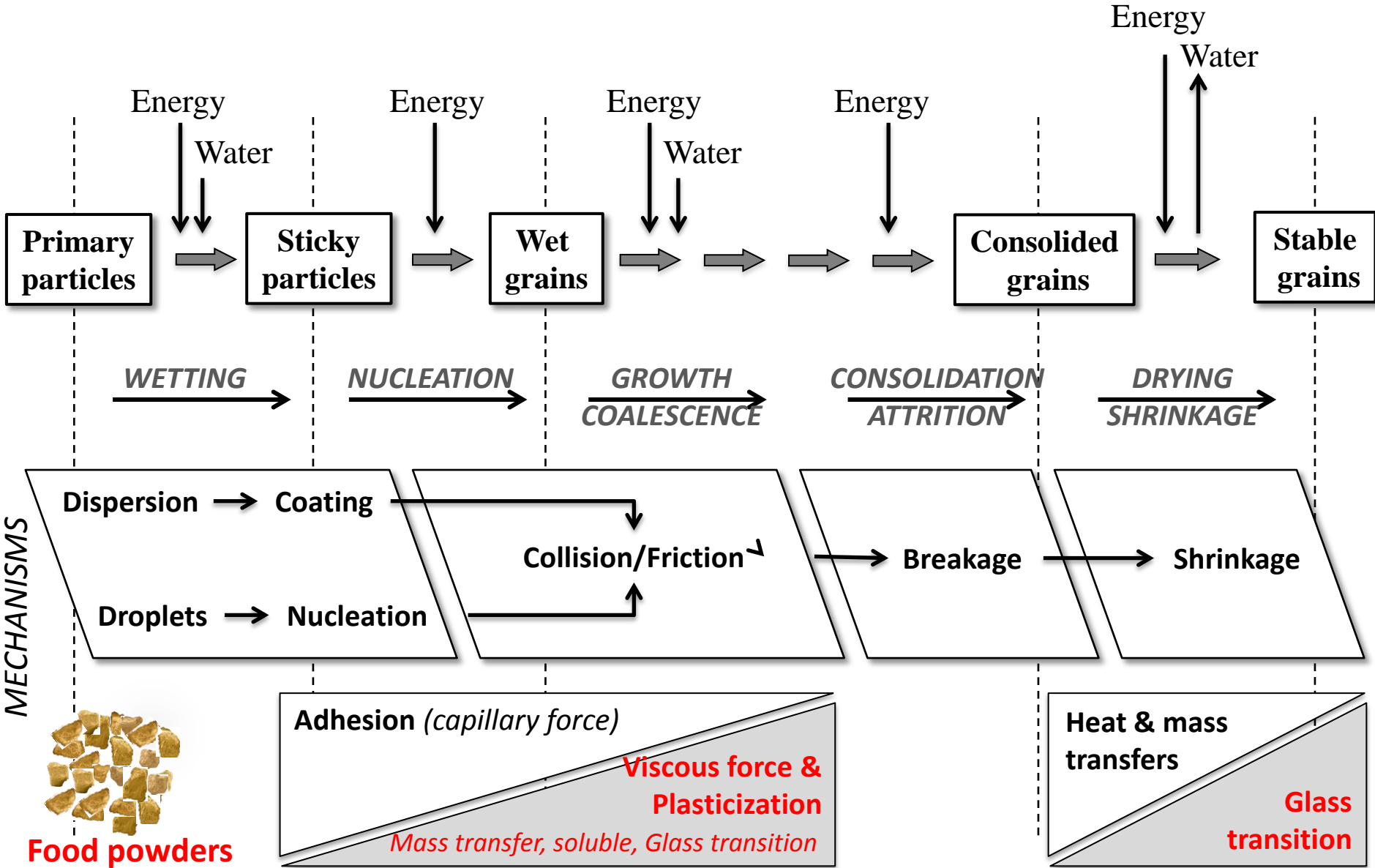




Growth & Drying - Mechanisms



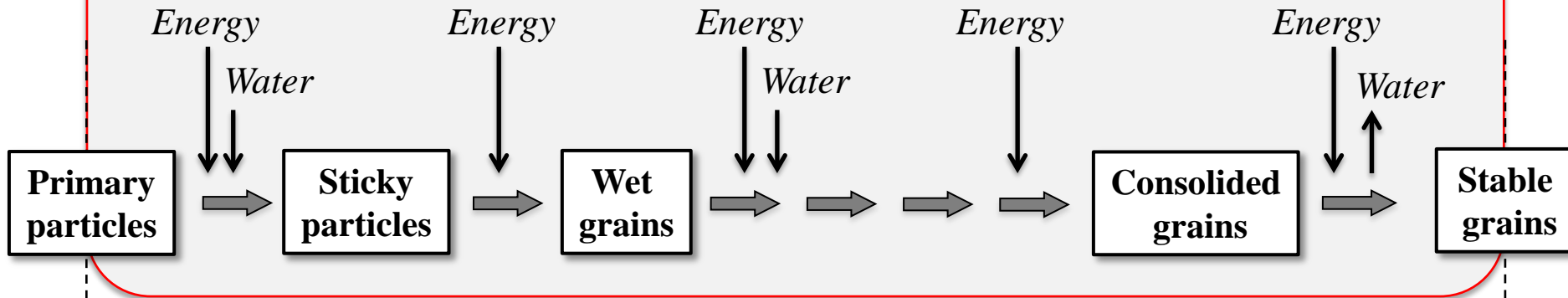
Growth & Drying – Reactive food powders





Coupled approach

Pneumatical energy – Thermal energy

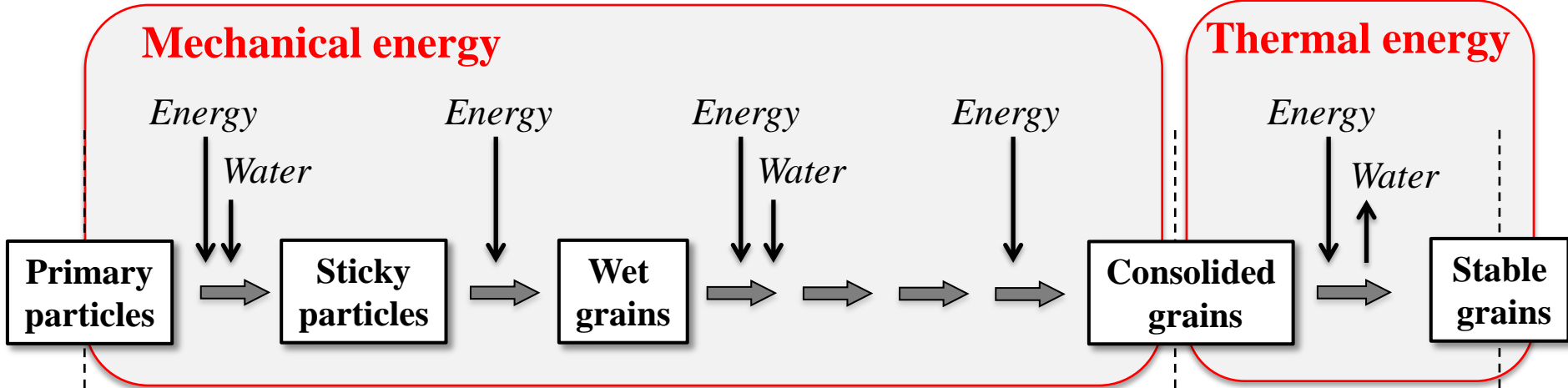


Spray drying/ Fluidized bed : Semolina is agglomerated when tap water is sprayed under a flow of hot air.

[Hydration + Growth + Reaction + Drying]



Decoupled approach

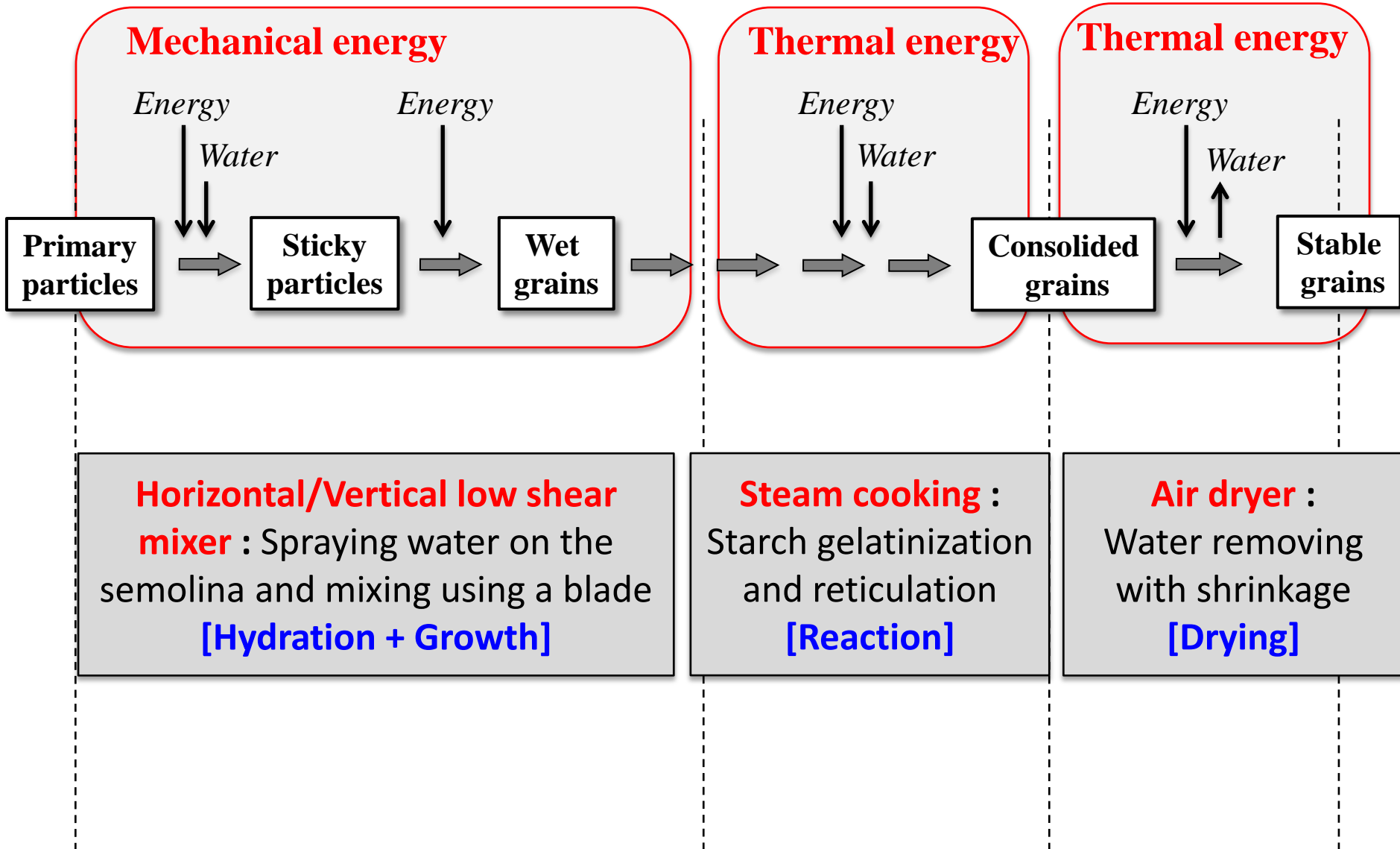


Horizontal/Vertical low shear mixer :
Spraying water on the semolina and mixing using a blade
[Hydration + Growth]

Air dryer :
Water removing with shrinkage
[Drying]



Decoupled approach





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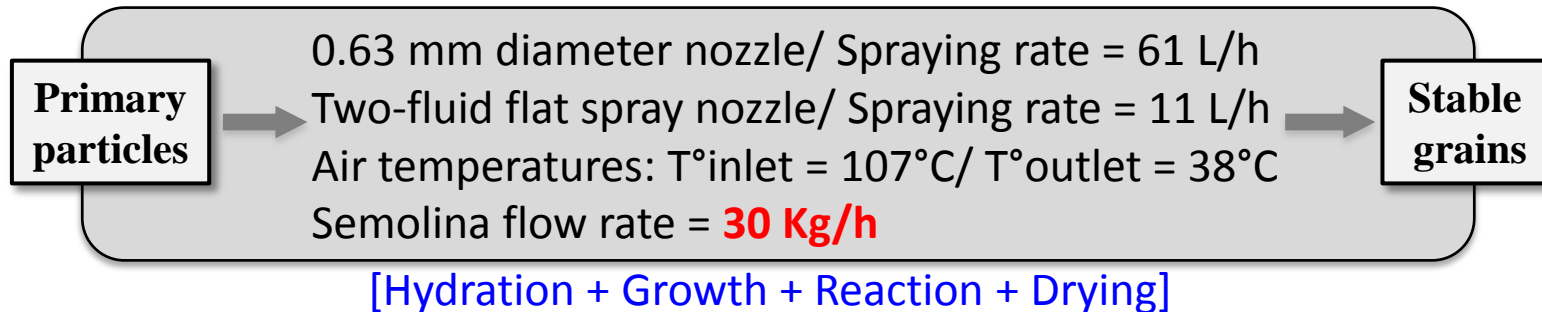
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Coupled approach

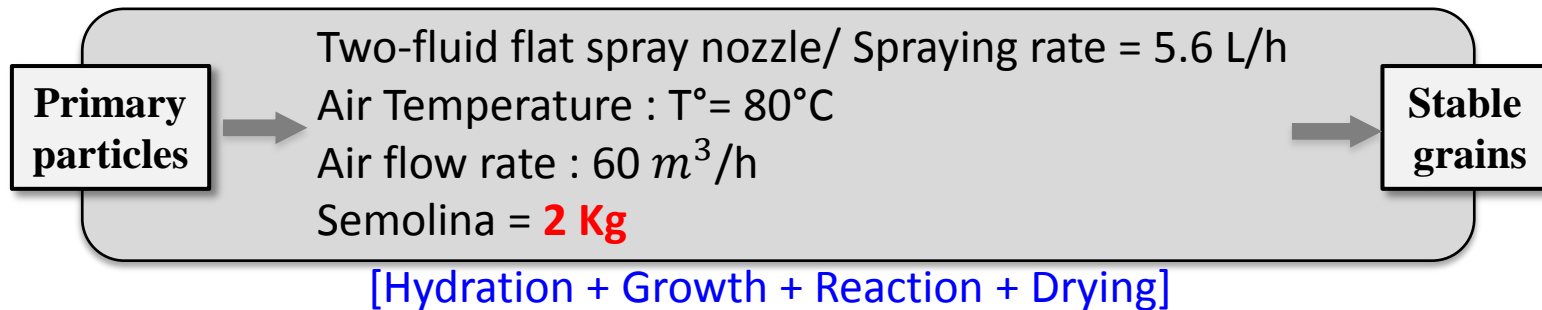
Raw Materials : Durum wheat semolina - Industrial couscous samples (1 & 2)

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

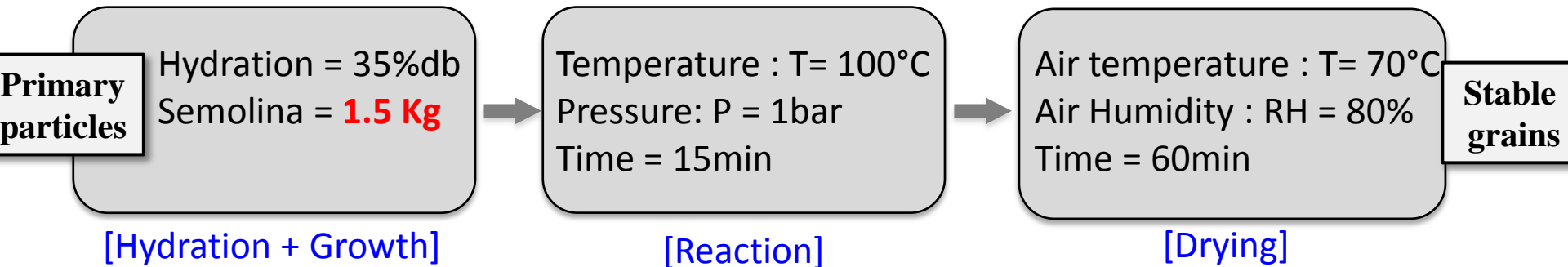


Decoupled approach

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>	Agglomeration yield (%)
<i>Coupled process</i>	Spray dryer	15.7
	Fluidized bed	47.6
<i>Decoupled process</i>	Horizontal mixer - dryer	17.7
	Vertical mixer - dryer	13.7
<i>Decoupled & reaction process</i>	Vertical mixer - cooker - dryer	12.5
	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

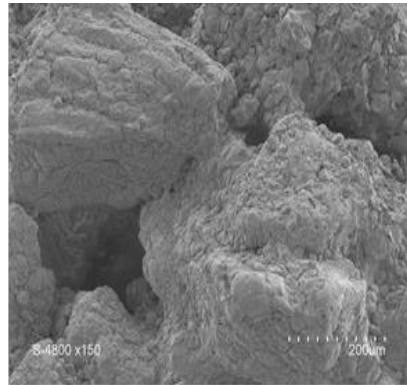
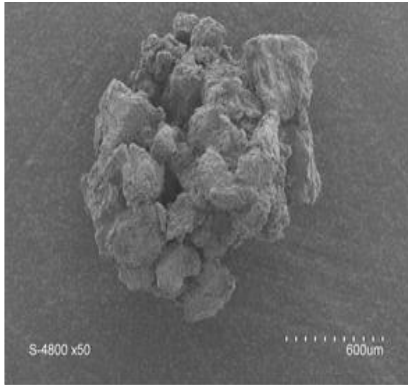
<i>Process</i>	<i>Technology</i>	Water content(%)_{db}	Starch gelatinization (%)
<i>Coupled process</i>	Spray dryer	10.2 (0.1) ^c	13.8 (1.9) ^b
	Fluidized bed	10.2 (0.1) ^{c,b}	10.0 (0.9)^a
<i>Decoupled process</i>	Horizontal mixer - dryer	9.3 (0.1) ^a	14.4 (1.3) ^b
	Vertical mixer - dryer	10.0 (0.1)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

- **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)*.

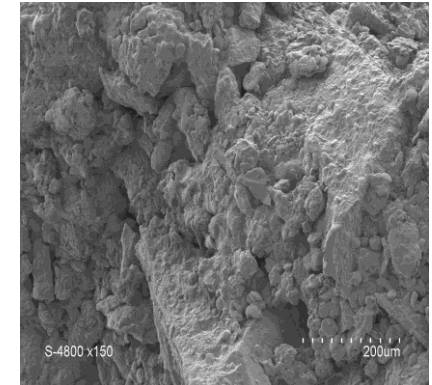
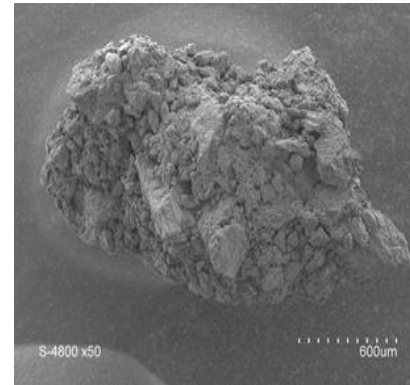
Microstructural scale

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

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

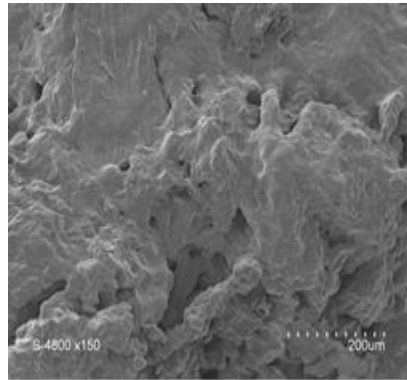
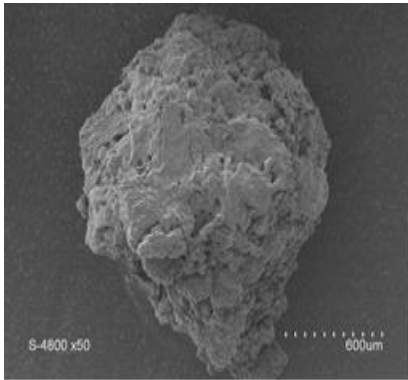
Microstructural scale (SEM)

Spray dryer
(magnifications X50 and X150)

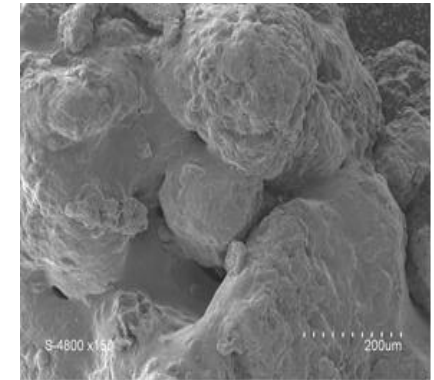
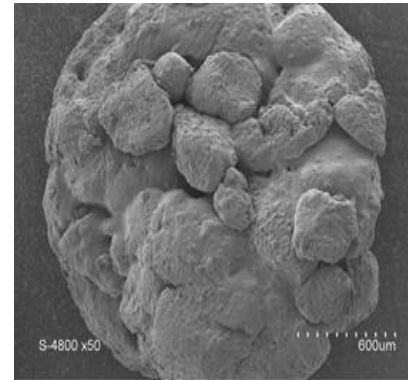


Vertical mixer - Air dryer
(magnifications X50 and X150)

- **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.

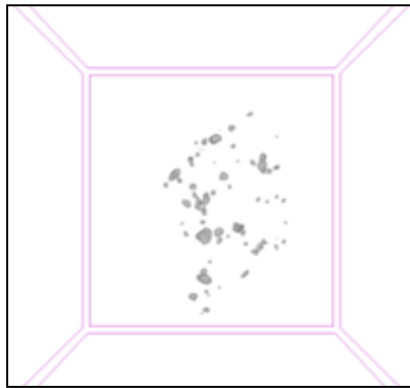
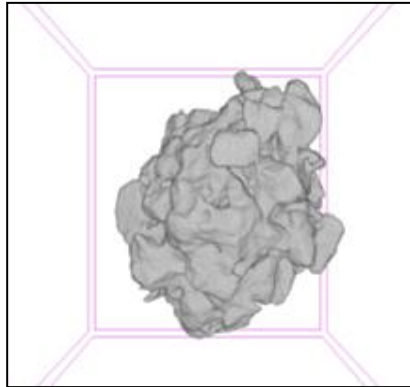
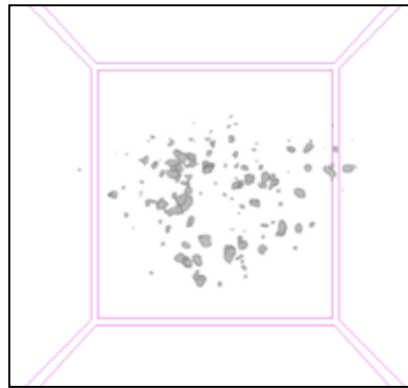
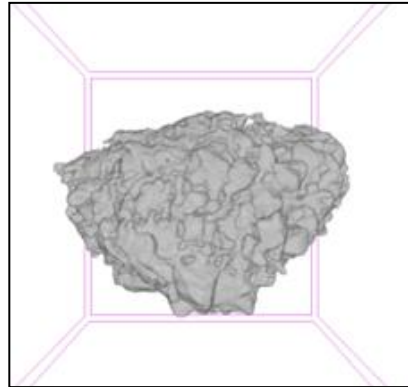
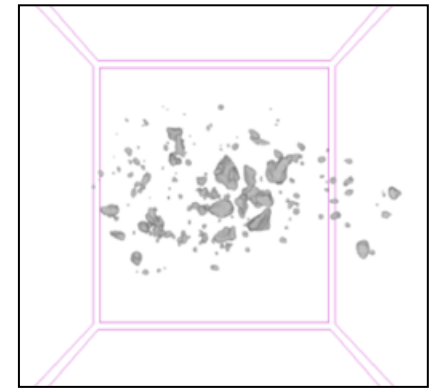
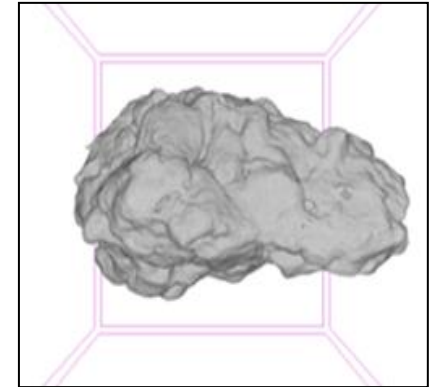
Microstructural scale (SEM)

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

- **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.

Functional attributes

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

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

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



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Conclusion

- 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