Designing attractive healthy high fibre products by using material science and rheology based guidelines

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Wageningen Food & Biobased Research

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CONTENT

- **Introduction**
- **Development of high fibre, zero sugar cakes:**

  science based approach
- Impact of bran on dough and bread quality –

  mechanisms
- Final remarks – future perspectives

Why dietary fibres?

Drivers

- Aging population drives fibre enriched products
- Increasing obesity and diabetes
- Demand for decreased sugar products
  - Incl. soft drinks and bakery products

- Clean label functional ingredients
- Sustainability and green chemistry
- Increased focus on plant based diets and renewable ingredients

> 30 Year old physico-chemical theories (‘40-’50) Application to starch and sugars (~ 70-’85)

A physico-chemical quantitative basis in addtion to the ‘usual’ biochemistry

Thermodynamics of High Polymer solutions," Paul J. Flory Journal of Chemical Physics, August **1941**, Volume 9, Issue 8, p. 660

Number average Molecular Weight Fox TG; Flory PJ, **(1950),** "Second-order transition temperatures and related properties of polystyrene", Journal of Applied Physics, 21: 581–591

Flory 1941 **Application to starch:** Lelievre J: Starch gelatinization. J Appl Polym. Sci. **1974**,

Effect of sugars: Evans ID, Haisman DR: The effect of solutes on the gelatinization temperature range of potato **starch**. Starch/ Starke **1982,** 34:224-231.

Predicting crumb hardness: Ashby – Gibson theory for cellular solids (foams and sponges) *Ashby, Metallurgical Trans A, 14A, 1755* ***(1983)***

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Innovation by adaptation for bakery products

Current Opinion in Food Science 2016, 9:117–125

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Available online at www.sciencedirect.com

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Current Opinion in Food Science

Rheological and thermal behavior of food matrices during processing and storage: relevance for textural and nutritional quality of food

Stefano Renzetti and Albert Jurgens

Conclusion

"(.....)The development of ***new physical and empirical models*** *and/or*

the ***adaptation of well-established models from polymer and material sciences***

in combination with ***characterization of rheological, thermal behavior and***

microstructure of food matrices

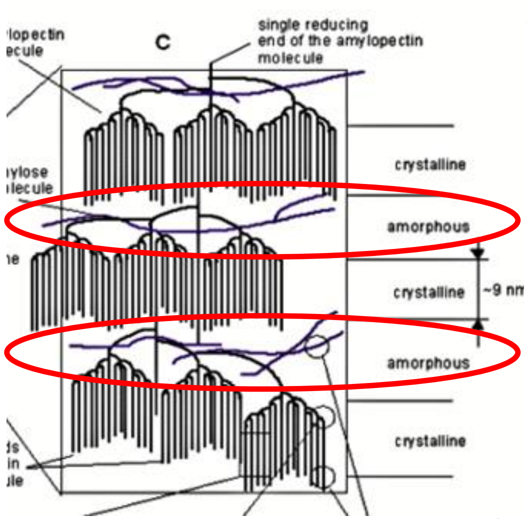
are valuable tools to develop such reformulation guidelines "

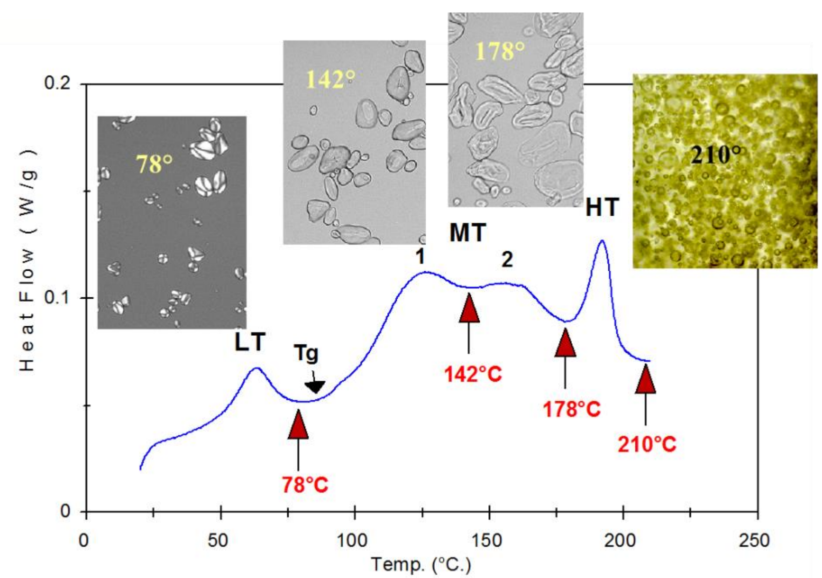
Importance of starch gelatinization for quality of bakery products

- The state transitions of starch, i.e. gelatinization and retrogradation, are essential determinants of the quality of bakery products
- In particular, the gelatinization process in cake products is a key quality which largely controls food matrix structure and final texture
- Therefore, understanding what modulates starch gelatinization in a complex bakery formulation, e.g. cake, is essential when one wants to reformulate

Starch gelatinization

- Involves different stages of re-organization. Detectable only at low moisture contents
- <u>Onset of gelatinization</u> determined by <u>transition of the amorphous layer</u>
- Sugars increase the glass transition temperature
  - with higher concentration
  - with higher molecular weight





LT= relaxation enthalpy (energetically favourable re-organization occurring below Tg

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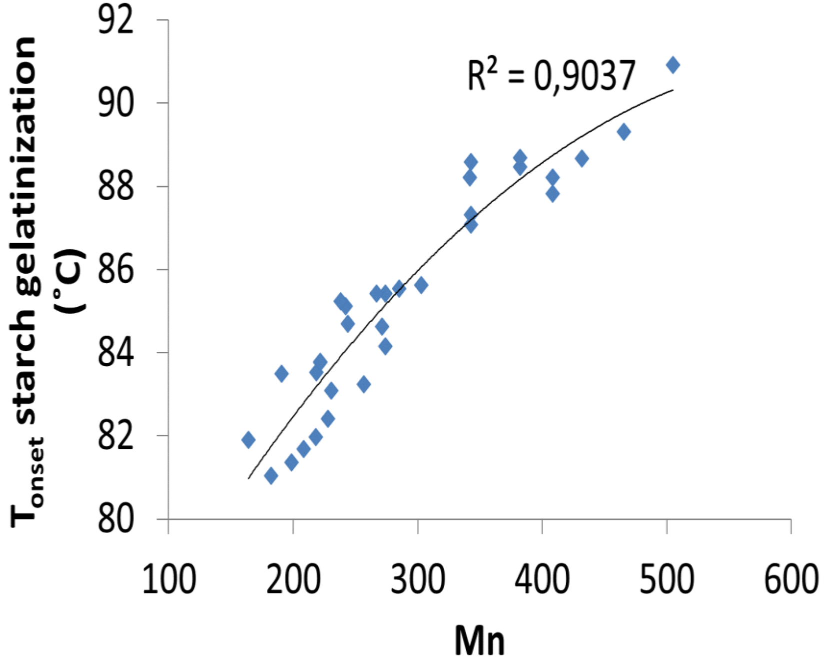
Predicting starch gelatinization temperature

- Following on the Flory-Fox theory: the **glass temperature increases** with the **number average molecular weight, M_n**

$$T_g = T_{g,\infty} - \frac{K}{M_n} \qquad \text{where } M_n = \frac{\sum n_i M_{w,i}}{\sum n_i}$$

M_n of sugars in cake batter well describes their influence on onset of starch gelatinization (at constant amount of total sugars)

Optimizing structure for onset temperature (i.e. T_{onset} of gelatinization) is key to modulate product quality



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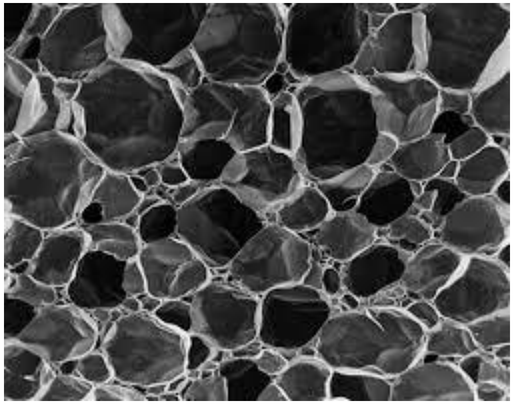
PREDICTING CRUMB HARDNESS

- Sugar replacement affects structure formation during baking
- Variation in the structure (e.g. crumb density) results in textural and baking quality deviations
- Crumb hardness and crumb density



Ashby – Gibson theory for cellular solids
(foams and sponges)
(Ashby, Metallurgical Trans A, 14A, 1755(1983)

- Crumb hardness: $CE_{film} \cdot (crumb\ density)^{n}$

foam n=3 , sponge n=2 *(bakery products: foams)*

E_{film}= elastic properties matrix
C= constant

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PREDICTING CRUMB HARDNESS

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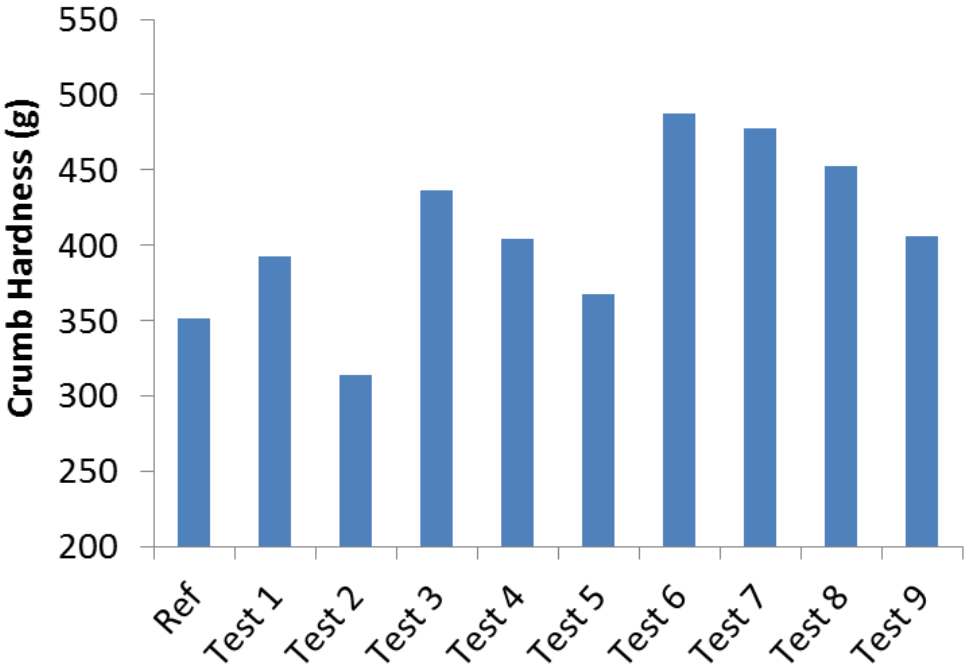
› **Example of application on 1 to 1 sugar replacement**

$$\boldsymbol{Crumb\ texture} = \{E_{matrix}, \Phi_{air}, \Phi_{fat}\}$$

Each test: different composition for replacing sugar



- Φ_{fat} can be considered constant (no reduction)
- Φ_{air} is related to crumb density, for which we can correct with Ashby-Gibson
- E_{matrix} depends on: (i) interaction of flour components with sugars (ii) fat distribution

  (iii) moisture content

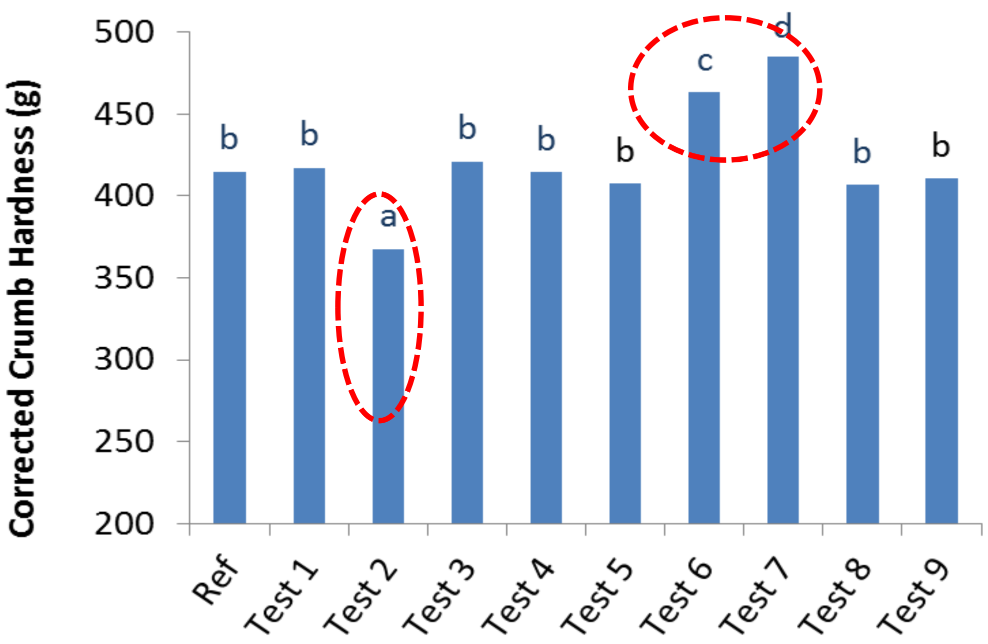
PREDICTING CRUMB HARDNESS

› **Example of application on 1 to 1 sugar replacement**

$$\boldsymbol{Crumb\ texture} = \{E_{matrix}, \Phi_{air}, \Phi_{fat}\}$$

Hardness corrected for influence of crumb density factors, related to Φ_{air}

Matrix properties are different for only 3 sugar replacers.



The influence of sugar replacers on **matrix properties**, $\boldsymbol{E_{matrix}}$, can be unravelled :

differentiation of effects of

- ❑ product density ($\boldsymbol{\Phi_{air}}$ **)**
- ❑ contribution to $\boldsymbol{E_{matrix}}$

(Note: Φ_{fat} does not vary)

Test 1 – 9: sugar replacers

HEALTHY REFORMULATION

- We know how to optimize T_{onset} of starch gelatinization
- We know how to modulate crumb structure, e.g. density
- We know how to select ingredients which do not alter E_{matrix}

- Application: using these tools / formulas to optimize cake formulation substantially reduced in sugar content
- **Even to replace all (~ 33%) added sugar!**

HEALTHY REFORMULATION

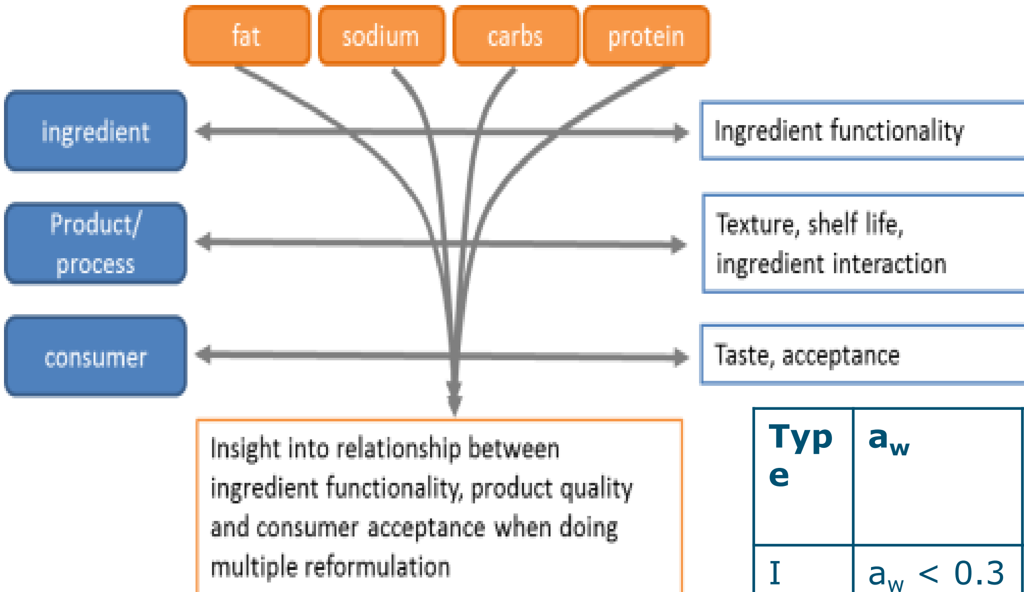
Peijnenburg spiced cake
(= ginger bread)
ZERO added sugar

Excellent taste
More expensive
High sales!

'Low sugar invention'

	Dutch spiced cake Peijnenburg	**Dutch spiced cake Peijnenburg ZERO**
In supermarket (475g)	EUR 1,70	EUR 2,02
Energy	***311 kcal***	***241 kcal***
Fats	1,3 g	1,5 g
Carbohydrates	***70,2 g***	***55,0 g***
of which sugars	***39,5 g***	***5,9 g***
Dietary fibre	***3,1 g***	***18,3 g***
Proteins	2,7 g	2,6 g
Salt	0,51 g	0,62 g
Composition includes	Glucose-fructose syrup, Rye flour (39%), Sugar	Rye flour (39%), Fibre (oligo-fructose) Sweetener (xylitol)

MULTIPLE REFORMULATION, open innovation platform, from ingredient to consumer 2013-2016



Type	a_w	Products	Multiple reformulation	Model system ingredients
I	$a_w < 0.3$	biscuit	fat, fibers, sugar	flour, fat, sugar, water
II	a_w 0.7-0.9	cake, honey cake	fat, protein, sugar, fiber	tbd, wheat & rye
III	a_w 0.7-0.9	vegetarian product, filet	protein, salt, (fat)	plant protein, gluten/fibers, water, salt
/	$a_w > 0.9$	ragout	fat, salt, starch	water, flour, salt, fat

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- Introduction
- Development of high fibre, zero sugar cakes: science based approach
- **Impact of bran on dough and bread quality – mechanisms**
- Final remarks – future perspectives

Impact of bran on dough and bread quality: mechanisms

Food Research International 102 (2017) 728–737

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Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Understanding the influence of buckwheat bran on wheat dough baking performance: Mechanistic insights from molecular and material science approaches

Check for updates

Miriam Zanoletti[a,b], Alessandra Marti[a], Mauro Marengo[a], Stefania Iametti[a], M. Ambrogina Pagani[a], Stefano Renzetti[b,*]

Aim and focus

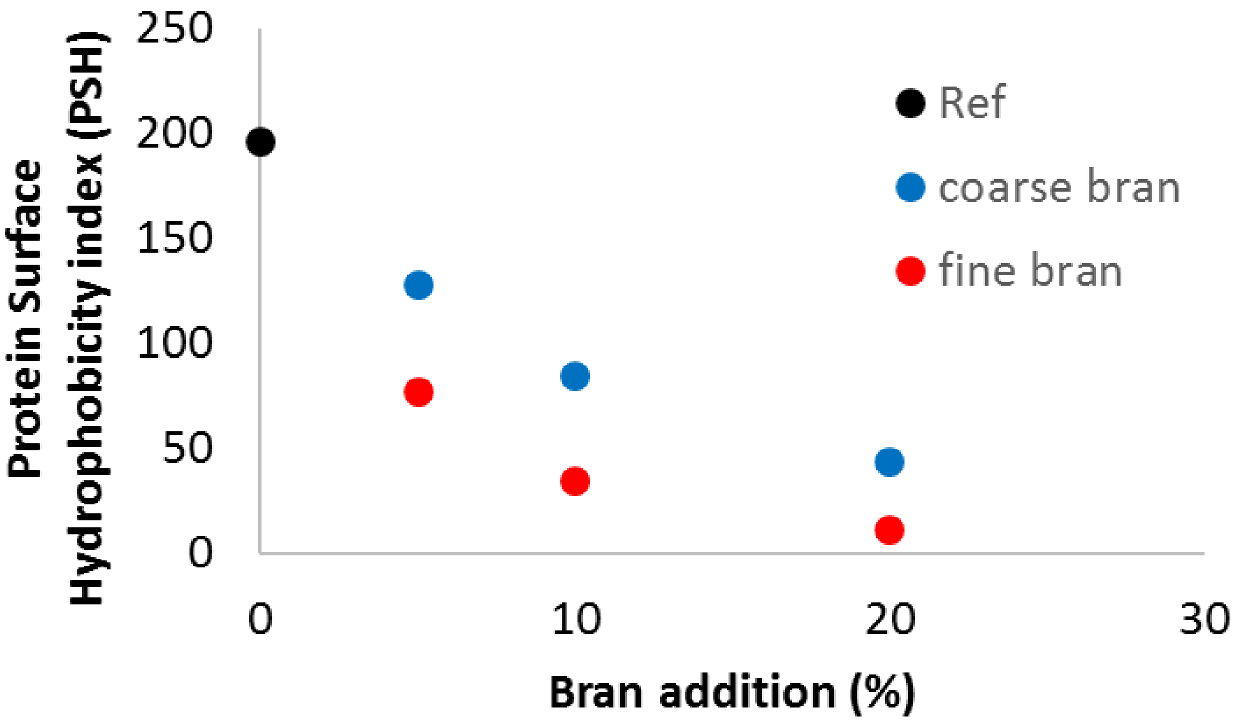
- Gather first insights on technological impact of bran addition to wheat dough based on molecular and material science approaches – by measuring/ using
  - Gluten solvation and structural arrangement in presence of bran
  - Thermodynamic principles describing the influence of bran on starch gelatinization
  - Crumb as a multi-phase mixed system controlling the apparent texture properties

Methods

- **Farinograph tests** → determine water absorption and mixing time
- **Solid state fluorescence** → assess protein surface hydrophobicity in dough
- **Dynamic Mechanical Thermal Analysis (DMTA)** → thermo-mechanical behaviour and phase transitions of starch
- **Standard baking tests and Texture Profile Analysis (TPA)**→ assess bread quality

PROTEIN SURFACE HYDROPHOBICITY STUDIES

Development of surface hydrophobicity of gluten hampered by bran especially fine bran:



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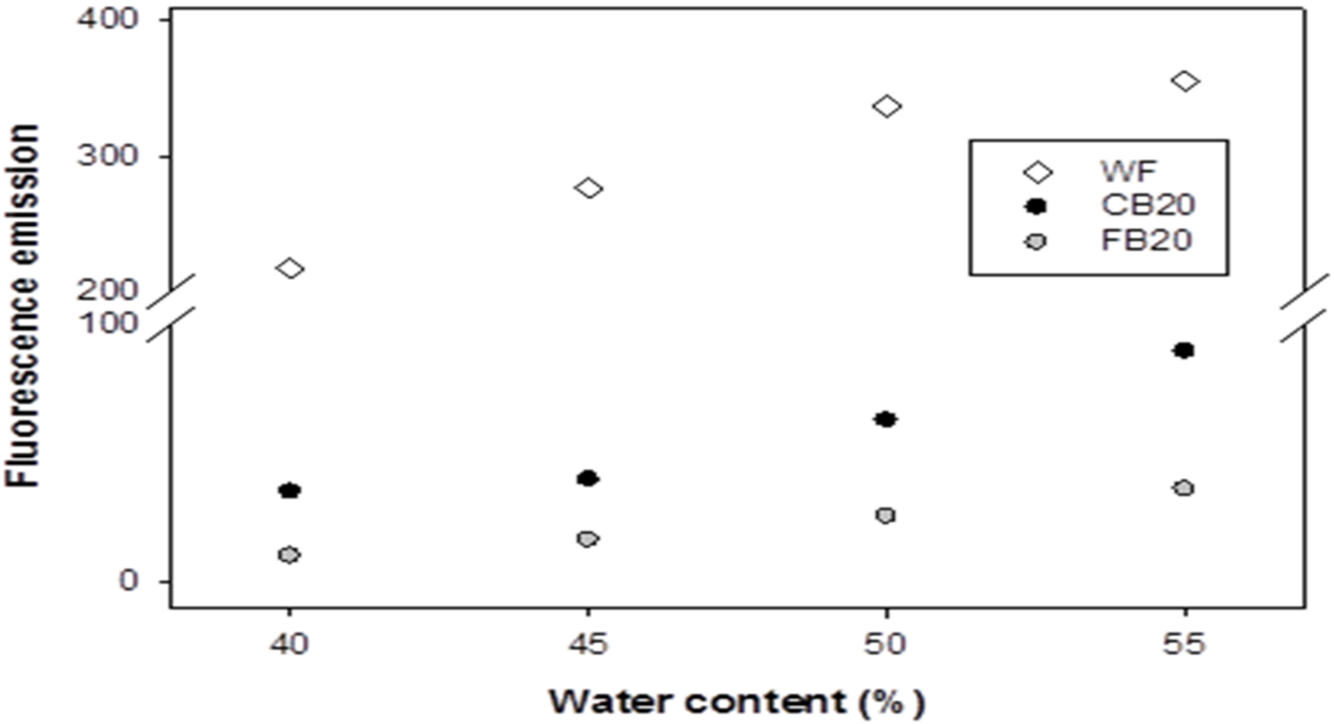
Gluten structure/ surface hydrophobicity and solvation



Gluten solvation hampered by bran – especially fine bran

Wheat : Gluten solvation almost complete at 45% water

Coarse Bran 20%: Solvation still progressing at 55% water

Fine Bran 20%: Major delay in solvation compared to coarse bran

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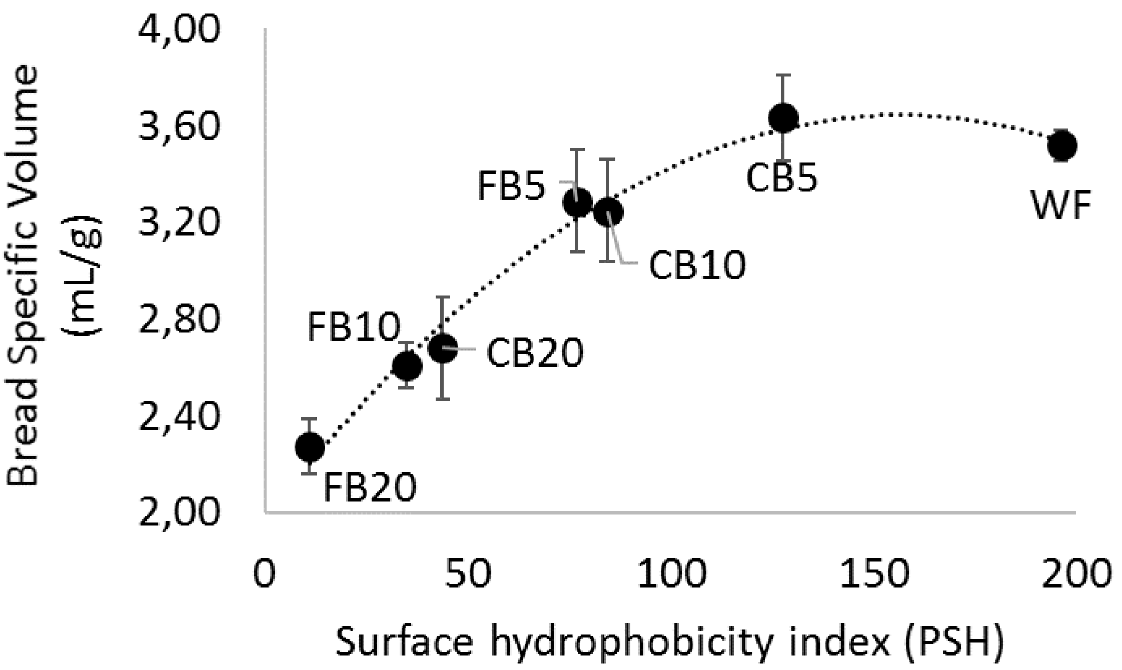
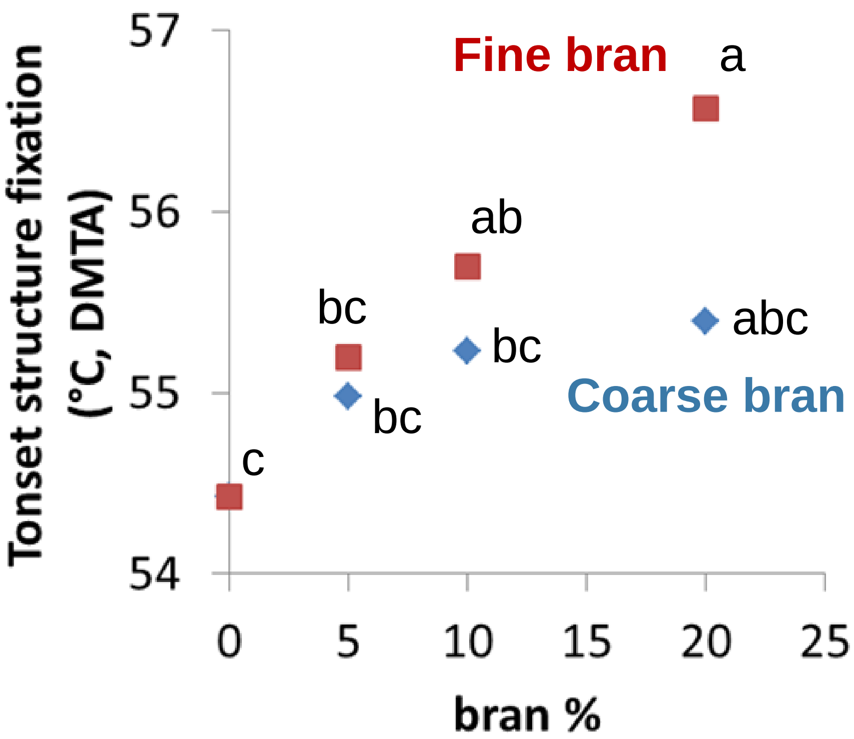
GLUTEN SURFACE HYDROPHOBICITY INDEX - BREAD VOLUME

- Baking performance related to observed changes in gluten structural arrangements / surface hydrophobicity Index



PHASE TRANSITIONS OF STARCH

Thermo-mechanical behaviour and impact of bran



- T_{onset} related to starch gelatinization

  (high correlation with DSC results)

- **T_{onset} of structure fixation increases with bran addition**

  strong increase with Fine Bran

Considerations

- Starch content decreases with bran addition
- Water content increases with bran addition

Increasing water:starch ratio → ***T_{onset} should decrease. However, T_{onset} increases***

PREDICTING T_{onset} OF STARCH GELATINIZATION

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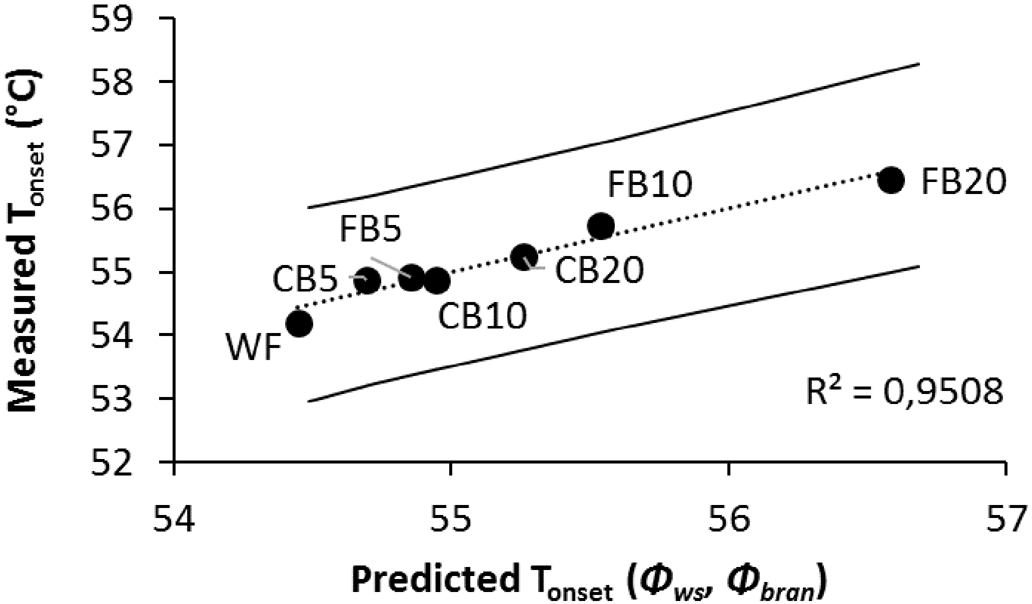
INFLUENCE OF % WATER, % BRAN, BRAN PARTICLE SIZE

- T_{onset} of gelatinization controlled by interplay of Φ_{water} and Φ_{bran}
- Well predicted with Flory-Huggins ($\frac{\mu_w}{RT} = ln(1-\Phi) + \left(1-\frac{1}{N}\right)\Phi + \chi\Phi^2$)

$\longrightarrow$ Presence of bran - Less water available for starch



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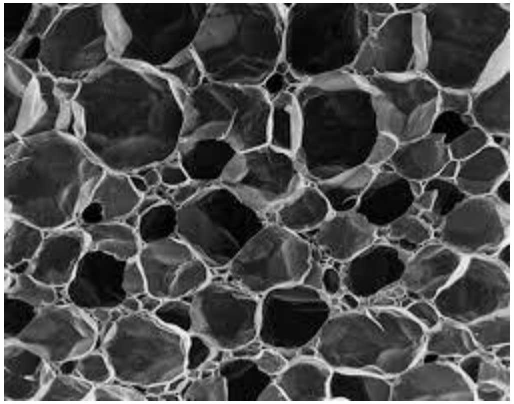
Crumb hardness and crumb density

Ashby – Gibson theory for cellular solids (foams and sponges)

(Ashby, Metallurgical Trans A, 14A, 1755(1983)



Crumb hardness: $CE_{film} \cdot (crumb\,density)^{n}$

foam n=3 , sponge n=2

E_{film}= *elastic properties matrix*

C= constant

PREDICTING IMPACT OF BRAN ON CRUMB TEXTURE

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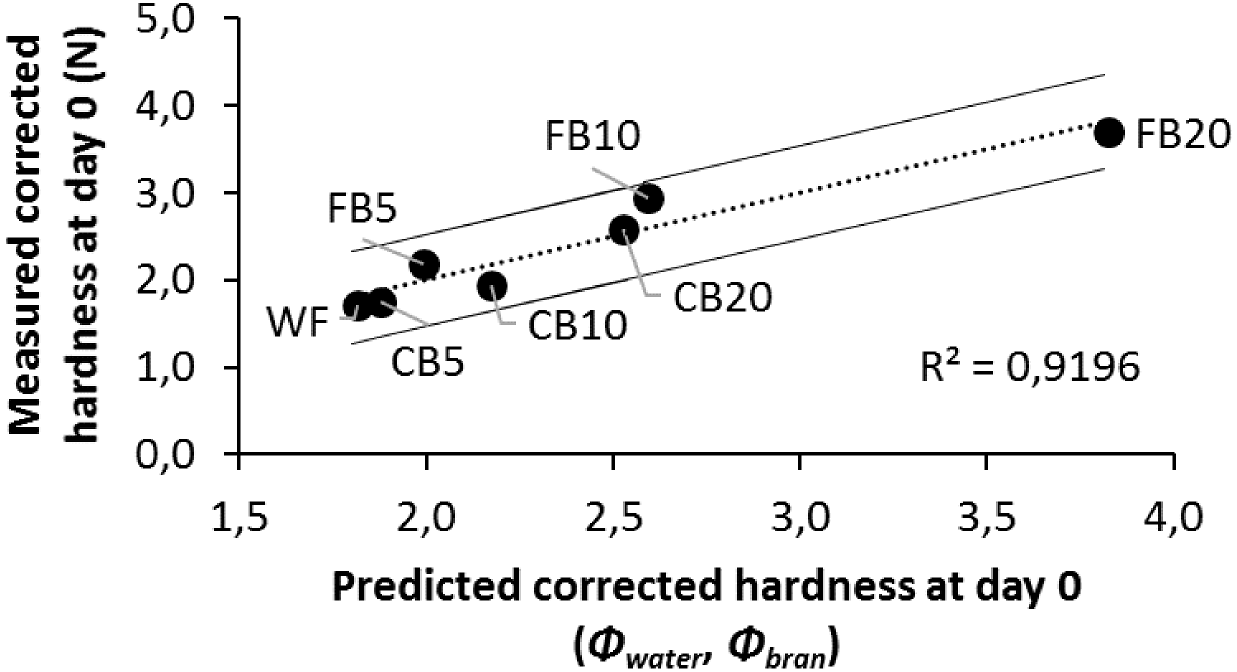
- Corrected hardness controlled by interplay of Φ_{water} and Φ_{bran}



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Conclusion

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- A key mechanism behind the effect of buckwheat bran is related to water availability and water partitioning within the polymeric matrix:
    - *Affect gluten solvation and structural arrangements*
    - *Modulate starch gelatinization and paste properties*
    - *Modulate crumb texture*

- in this study, Φ_{water} and Φ_{bran} computed from dough and bread composition, could well describe variations in T_{onset} and in crumb texture (with crumb considered as a cellular solid)

- Gluten structural arrangements probed by surface hydrophobicity studies were strongly related to baking performance.
- Such approach seems relevant for future studies

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Perspectives OF more powerful complex models

Dr Stefano Renzetti
Senior scientist
Wageningen Food and
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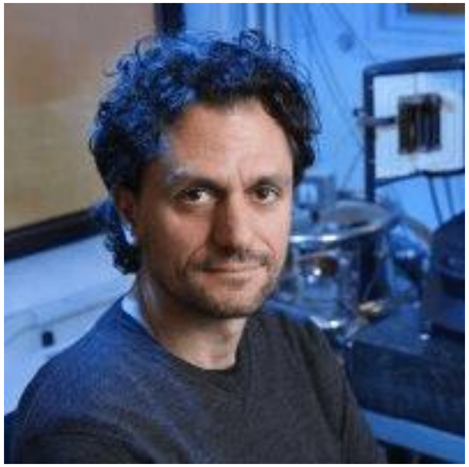

Basis for current and future developments lays on multidisciplinary approaches, including fruitful collaborations with University of Milan

Our 1st model was developed for sugar reduction only.
We can now, with the extended model, combining different physical theories , predict the ***onset of starch gelatinization*** for major variations in
sugar mixture : water : flour ratio's
as well as ***sugar compositions***".
This and other key processing aspects have been translated in a practical recipe formulation tool for our current industrial partners

Molecular structure features, such as gluten surface hydrophobicity, can provide a basis for explaining gluten properties and behaviour.
With this basis, material sciences and biochemistry can together provide more detailed explanations

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PHYSICAL MODELS FOR BAKERY PRODUCT REFORMULATION

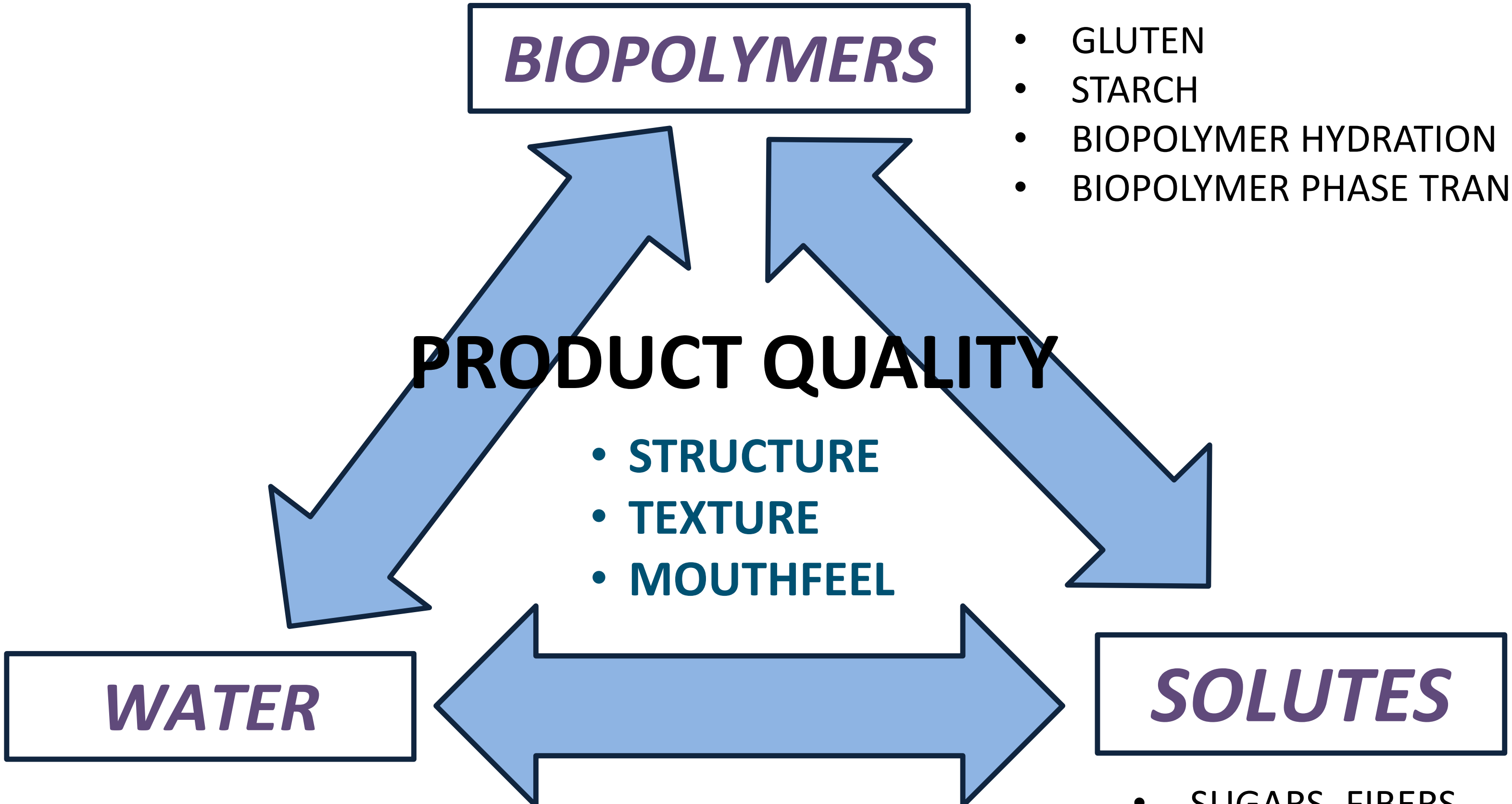
- Flory-Fox theory describing ***T_g of biopolymers***: $T_g = T_{g,\infty} - \frac{K}{M_n}$

- Flory-Huggins theory for ***biopolymer melting***: $\frac{1}{T_m} - \frac{1}{T_m^{\circ}} = \frac{R}{\Delta H_U} \frac{v_U}{v_W} [\Phi_W - \chi \Phi_W^2]$

- Flory-Huggins theory for ***water partitioning***: $\frac{\mu_w}{RT} = ln(1 - \Phi) + \left(1 - \frac{1}{N}\right) \Phi + \chi \Phi^2$

These theories can be conveniently combined to describe the influence of reformulation on the food structuring process

Relevance of Ingredient interactions



- GLUTEN
- STARCH
- BIOPOLYMER HYDRATION
- BIOPOLYMER PHASE TRANSITIONS

- SUGARS, FIBERS

MODELS - IMPLICATIONS FOR PRACTICE

- **Translated in recipe processing tool for current industry partners**
  This quantitative model: preferred by experienced operators over their own ‘gut-feeling

- **Prediction of (un-)favourable impact of various fibres (and Mw) on bread volume**

- **Powerful and effective tools for**
  - New projects towards healthier product formulations
  - Tools for process control in cases of compositional changes

- Models will help in creating success in new projects for sugar reduction and for increase of fibre content.

New Public Private Partnership project

Getting fiber ingredients applied

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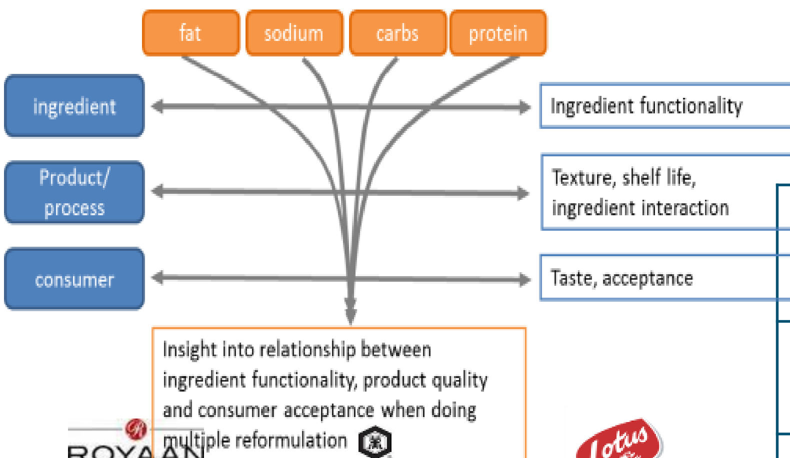
As in the previous successful PPS (see below) – Wageningen is inviting industry partners to join

For more info – contact joost.blankestijn@wur.nl

MULTIPLE REFORMULATION, open innovation platform, from ingredient to consumer 2013-2016



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/	a_w >0.9	ragout	fat, salt, starch	water, flour, salt, fat

ROYAAN KIKKOMAN Lotus BAKERIES SENSUS Zeelandia PEIJNENBURG ENKCO WAGENINGEN UR For quality of life TNO innovation for life

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