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RSM as a tool for optimizing the formulation of a sorghum-based salted biscuit that can be rotary-molded

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Introduction

This work was carried out as part of a Proof of Concept project funded by Carnot Qualiment.

Its objective was to study the feasibility of making gluten-free biscuits made from sorghum with the simplest and healthiest formulation.

The formulation had to be compatible with the use of industrial rotary molding technology used in biscuit factories, thus enabling larger scale production.

Sorgho : a response to societal challenges



Sorghum

- 5th most cultivated cereal in the world [1]
- Agronomic advantages**
 - Heat and insect resistant
 - Relatively short growth period
- Ecologic transition**
 - Moderate water and fertilizer requirements
- Nutritional and Health benefits**
 - Gluten free
 - Presence of macro and micro-nutrients
 - Bioactive substances
- Applications** : in human food (Africa, Asia) but mainly intended for animal feed (Europe)

- ### Aims
- Manufacturing sorghum flour-based salted biscuits. One health approach (whole grain flour, low fat and salt contents). **Naturality** (using a simple recipe with no additives).
 - Using RSM to study the effect of dough hydration and its oil content on multiple dough characteristics as well as those of corresponding biscuits.
 - Designing a recipe compatible with the industrial rotary molding technology used in the biscuit industry.
 - Developing a new sustainable sorghum sector for human consumption.



Laboratory rotary molder (AgroParisTech Campus, Palaiseau)

Materials and Methods

Manual manufacturing biscuits and analyses [2]

- 300 g of dough containing:
 - a mix of whole grain flours (S/CP) as follow:
 - 75% white Sorghum flour (cultivar Arabesk)
 - 25% Chickpea flour
 - or whole Wheat flour as control
- Water
- Salt (1.2 % of the dough)
- Oleic sunflower oil

Mixing
Rolling
Cutting
Baking
Resting

Analyses of the dough :
viscoelastic and rheological properties of the doughs through the determination of elastic (G') and viscous (G'') modulus in the linear deformation domain, maximum force reached during a 20% dough compression (Fmax comp) and relaxation index (RI) were measured using a rotational rheometer (Kinexus Lab+, Netzsch).

Wheat (control)



S/CP

Analyses of the biscuits :
Aw, water content, density, dimensions, volume, spreading ratio and hardness.

Experimental design

- A two-factors centered composite design (dough hydration and oil content) with five replicates of the center point for uniform accuracy was realized [3] (Table 1). Three checkpoints were also carried out.

Table 1 : Centered and real coordinates of the studied factors

Centered coordinates (x) and real coordinates (X)								
Centered coordinates (x)	-1.414	-1	-0.5	0	0.5	1	1.414	Step
Dough hydration (% wb) (X1)	25.00	25.73	26.62	27.50	28.38	29.27	30.00	1.77
Oil content (% wb) (X2)	11.50	12.01	12.63	13.25	13.87	14.49	15.00	1.24

- The effects of the experimental centered composite design were described by the following second order polynomial model:

$$Y = b_0 + b_1 x_1 + b_2 x_2 + b_{12} x_1 x_2 + b_{11} x_1^2 + b_{22} x_2^2$$

where Y was the predicted response, x_1 and x_2 the centered coordinates related to respectively dough hydration and oil content, b_i the coefficients of the effects of the factors (b_0 the mean of the responses; b_1 the linear effect of dough hydration; b_2 the linear influence of dough oil content; b_{12} the influence of interaction between dough hydration and oil content; b_{11} the quadratic influence of dough hydration and b_{22} the quadratic influence of oil content).

- The results were analyzed using the Statgraphic Centurion V19.1.3 software developed by Statpoint Technology, Inc. The repeatability was estimated thanks to the replicates performed at the central point of the experimental domain. This estimate was used to evaluate, using a Student test, the significance of the coefficients calculated for the models. The acceptance threshold chosen was 5%.

Results

Viscoelastic, rheological properties and aspect of the dough

Table 2 : Recorded effects of some viscoelastic and rheological characteristics of the dough.

Coeff	Elastic Modulus (G')	Fmax-comp	RI
	R ² =0.73	R ² =0.97	R ² =0.84
b ₀	4.19E+05	26.70	87.26
b ₁	-8.08E+04	-11.43	1.52
b ₂	-7.14E+04	-7.17	0.99
b ₁₂	-3.69E+04	1.35	-2.16
b ₁₁	-2.73E+04	-0.21	-3.02
b ₂₂	-4.29E+03	1.81	-0.36

R² indicates the % of the response variability explained by the polynomial model. In bold : coefficients that are significantly different from zero to 95.0% confidence level.

- The hydration of the dough and its oil content both had a negative linear effect on G' and on the Fmax-comp (table 2).
- The dough had a more elastic than viscous structure (G' > G'') (not shown).
- S/CP doughs exhibited G' values between 5.33.10⁴ Pa and 1.62.10⁵ Pa, with a mean of 4.19.10⁵ Pa for the central points of the domain. This average was four times higher than the values recorded for a control dough made from wheat (G' = 1.31.10⁵ Pa).
- The elastic structure of the S/CP dough was therefore weakened with the increase in the percentage of hydration and oil added to the dough, the effect of hydration being greater than that of the oil content.
- Fmax-comp determined the maximum force to compress the dough by 20% and characterized its consistency. The Fmax-comp measured at the center of the experimental domain were 26.7 N. The lower the percentage of hydration and oil in doughs, the more difficult it will be to compress them because the more consistent they will be.
- The high values of Fmax-comp were recorded for low hydration doughs that were drier, grainy and lacked cohesion (Fig 1(a)). Doughs with a high hydration percentage were more cohesive.
- The hydration of the dough had a positive linear effect and a negative quadratic effect on the RI. A significant negative interaction between the hydration and the oil content on this rheological characteristic was also observed (table 2).
- RI reflected the behaviour and time taken by the dough to relax following the compression stress. It may be related to the elasticity of the dough. The higher it was, the more the dough relaxed and the more elastic it was.
- RI values ranged from 76.72% to 88.45% , with an average of 87.26% for the points at the center of the domain. An optimum was achieved for formulations close to the center of the experimental (27.5% hydration of dough) (Fig 1(b)). The doughs with the highest RI (between 86% and 87%) corresponded to the points of the experimental domain with a percentage of hydration of the dough close to that of the center of the experimental domain.
- These observations could be related to those made on appearance and texture of the dough and also on its processability with rotary molding technology (Table 3).

Characteristics of the biscuits

Table 4 : Physico-chemical and physical characteristics of the biscuits.

	Aw	Water content	Hardness	Spread ratio	Volume
	R ² =0.431	R ² =0.665	R ² =0.738	R ² =0.673	R ² =0.65
b ₀	0.134	1.62	23.72	8.22	7405
b ₁	0.021	0.27	3.93	-0.84	708
b ₂	-0.006	0.07	-0.22	-0.28	300
b ₁₂	-0.010	0.02	-1.96	-0.16	112
b ₁₁	0.001	0.03	-0.83	0.39	-237
b ₂₂	-0.004	-0.19	-2.02	0.20	-156

R² indicates the % of the response variability explained by the polynomial model. In bold : coefficients that are significantly different from zero to 95.0% confidence level.

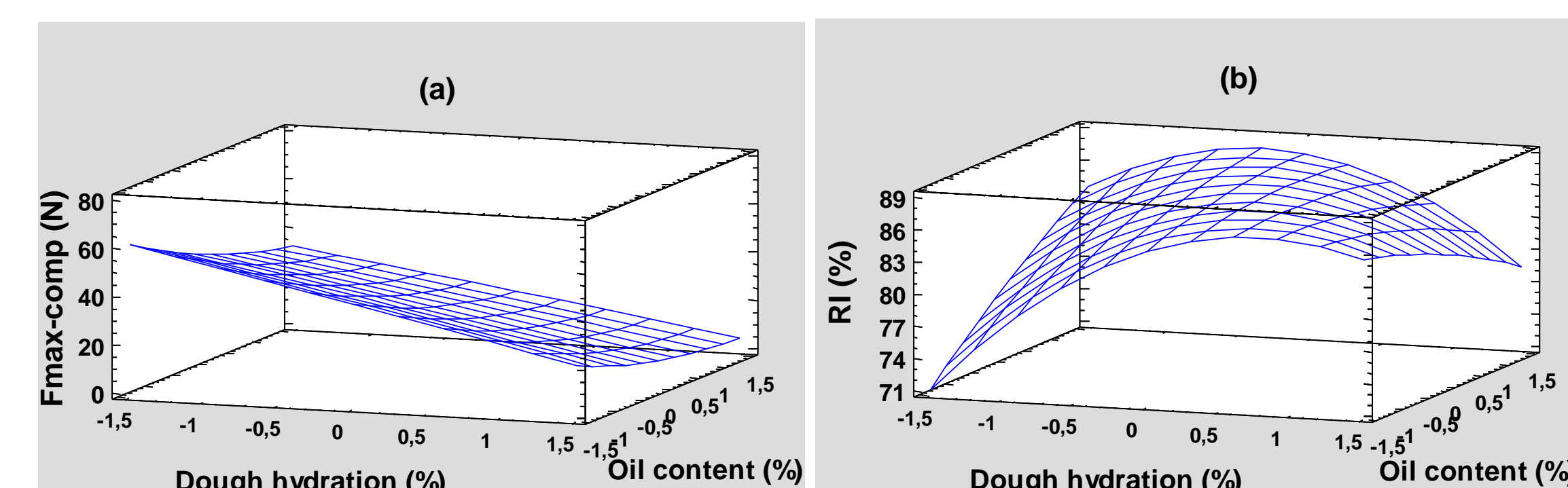


Fig. 1 – Surface response of Fmax compression (a) and relaxation index (b) of the dough as a function of dough hydration and oil content.

- The dough containing 27.50% (wb) water and 13.25% oil (center point) successfully lead to rotary molded biscuits (table 3). The dough with 25.73% (wb) water content and 12.01% oil was difficult to process by rotary molding. Finally, the dough with 29.27% (wb) water content and 14.49% oil was impossible to process with this technology

Table 3 : Trials with a laboratory molder

(x1) Dough Hydration (% wb)	(x2) Oil content (% wb)	Aspect and texture of the dough	Processability with rotary moulding
(0) 27.5	(0) 13.25	Cohesive with large blocks that do not disintegrate.	Successful
(0) 27.5	(1) 14.49	Cohesive, oily, sticks slightly to the fingers.	Difficult
(1) 29.27	(1) 14.49	Soft, very cohesive with a single block, sticks to fingers	Impossible
(-1) 25.73	(-1) 12.01	Dry, grainy, lacks cohesion and disintegrates	Difficult

Conclusions

- The dough hydration had a major influence on the viscoelastic structure, the consistence and the elasticity of the dough.
- The dough became more cohesive and adhesive with the increase in water content, while the biscuits became harder, with an increase in their volume and a decrease in their spreading ratio.
- The most critical parameter to control is then the water content of the dough, with a very narrow optimal window (i.e. low water content) for rotary-molding ability that was correlated to the maximum of the dough RI measured on the whole experimental domain.

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