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Predicting the quality of wheat flour dough at mixing using an expert system

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ABSTRACT

Modelling the links between the mixing process conditions of wheat flour dough and the properties of the dough is a challenge. This paper presents a systematic modelling approach based on qualitative algebra to represent human expertise in this domain. Qualitative models of wheat dough mixing have been implemented as an expert system, called *Ascopain*. The relations between the process conditions – flour specifications and kneading conditions – and the dough sensory properties, have been formalised by means of qualitative functions. An extensive evaluation of *Ascopain* is provided by comparing the simulation results, first to experts' predictions, and second, to experimental results of sensory evaluation of mixed dough properties. The good matching level proves the accuracy and the robustness of the expert-system and, overall, its ability to implement a reasoning on the influences of process conditions to predict actual dough properties, starting from ingredient characteristics.

Nomenclature

Notations	Description (unit)	Standard value for French bread
Flour specifications		
pc	Protein content (% dry matter)	10.5–11.5
ds	Damaged starch (UCD_Chopin Dubois Unit)	18–21
mc	Moisture content (% dry matter)	14–15
pent	Pentosan content (% dry matter)	2.2–2.8
aa	Amylolytic activity evaluated via Hagberg falling number(s)	250–300
ge	Gluten extensibility (cm)	1–10
gr	Average flour particle size/granulometry (μm)	70–90
st	Storage time (day)	7–15
fe	Extraction ratio (%)	77–80
sp	Soluble protein content (% dry matter)	≤20
wac	Flour water absorption capacity	–
Recipe		
hy	Dough hydration (% dough)	60–62
ls	Dose liquid sourdough (% dough)	0
po	Dose poolish (% dough)	0
gp	Dose gluten powder (% flour)	0
slt	Dose salt (% flour)	1.8–2.2
ss	Dose stiff sourdough (% dough)	0
fd	Dose fermented dough/sponge (% dough)	0
ye	Dose yeast (% flour)	1–3
Kneading process conditions		

(continued)

Notations	Description (unit)	Standard value for French bread
Tem	Temperature at the end of the kneading (°C)	22–26.2 (oblique-axis mixer)
Cbm	Dough consistency at the onset of kneading (UB_Brabender Unit)	350–450
ΔT	Total increase of dough temperature at kneading (°C)	5.5–10.5 (oblique-axis mixer)
Dls	Difference of linear velocity between the bowl and the rotor's arm of the mixer	–

1. Introduction

Mixing is one of the first operations of the breadmaking process; it influences significantly the dough processability during the following operations and the final quality of the bread. The properties of the mixed dough are influenced by the ingredients – flour specifications and recipe – the processing conditions and the type of mixer. Basically, mixing includes two successive stages: firstly, an initial mixing at low speed, for 2 to 4 min, to hydrate ingredients, called "ingredient blending", and, secondly, the texturing stage at higher speed for 8 to 20 min, called "kneading", that promotes a more homogeneous blend, through an intensive work input, weaves the gluten network and entraps air (Bloksma, 1990). Despite a great deal of studies about dough mixing, the accurate understanding of the dough formation is still incomplete (Stauffer, 2007). Indeed, this operation is difficult to model

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quantitatively with mechanistic approaches (Della Valle et al., 2014; Seguí, Barrera, Oliver, & Fito, 2007), because of the multiple interactions between dough composition, rheology and mixing conditions. Binding, Couch, Sujata, and Webster (2003), and Connelly and Kokini (2004) have used computation fluid dynamics to model the dough kinematics for different mixing conditions, but without fully integrating the complex flow geometry and behaviour of wheat flour dough. Lamrini, Della Valle, Trelea, Perrot, and Trystram (2012) developed an artificial neural network to predict dough temperature and power dynamics, but its application is restricted to one type of mixer and a specific dough formulation. None of these models can be applied directly to predict mixing performances in various conditions, at the laboratory or in a bakery, nor to predict dough properties.

Conversely, experts (technologists) in breadmaking, can reason efficiently over a variety of production contexts; they have a rich knowledge about the relations between the flour constituents, the ingredients and the mixing process conditions with the dough properties, which they evaluate by sensory measurements (Allais, Edoura-Gaena, Gros, & Trystram, 2007); this knowledge is hardly exploited in all these models, and "Bread Advisor" is one of the few software based on expert knowledge that proposes information about processing, and diagnoses possible defaults (Young, 2007). Experts (technologists) describe dough properties by qualitative, sensory vocabulary, like "consistent", "sticky",and "extensible" dough, implicitly referring to rheology (Elia, 2011). A challenge is to represent explicitly this type of knowledge in a computer system (Allais, Edoura-Gaena et al., 2007), so that mixed dough properties can be simulated. In this purpose, knowledge representation formalisms used in artificial intelligence (AI), like production rules, fuzzy logic or qualitative reasoning, are well adapted to work at the linguistic level (Perrot et al., 2004). Fuzzy logic is very popular in the food domain to design decision support systems (Edoura-Gaena, Allais, Gros, & Trystram, 2006; Linko, 1998). However, standard fuzzy rules "If *x* is a then *y* is b" are not expressive enough to convey the knowledge about the process, the product and their behaviour, expressed by rules like "the higher *x*, the higher *y*" (Bellazzi, Ironi, Guglielmann, & Stefanelli, 1998). Of the wide range of AI approaches, qualitative reasoning is an effective means of representing causal linkages of systems since it allows to model decision tables or expert rules as qualitative functions. Such functions have the capacity to represent explicitly the knowledge about the influences between properties (Dieng, Corby, & Lapalut, 1995). Using this approach, two qualitative models have been built to represent the expert knowledge on dough mixing, a first one for the "kneading" (Ndiaye, Della Valle, & Roussel, 2009), and a second for the "ingredient blending" (Kansou, Della Valle, & Ndiaye, 2012). Together, they have led to the development of an expert system called *Ascopain* (ASsemblage de COnnaissance sur la fabrication des PAINs Français, i.e. knowledge assembly on French breadmaking), that predicts the mixed dough properties starting from the flour specifications, the recipe and the mixing conditions.

The goal of this paper is to assess the ability of *Ascopain* to integrate the expert knowledge and to predict the dough properties in various mixing conditions. In this purpose, we first present the modelling principles of the expert system. Then we describe the experimental tests performed by experts and a test baker. The third section presents the comparison of these experimental results with *Ascopain* predictions.

2. Methodology

2.1. Modelling approach

We recall here the main steps of the approach described in detail by Ndiaye et al. (2009) in the case of the kneading stage, and extended to ingredient blending stage by Kansou et al. (2012).

2.1.1. Expert knowledge and assessment of dough properties

We have worked with two expert technologists that have a good theoretical background and have also written research articles in baking science and technology (Oury et al., 2010; Roussel, 2005). They have contributed to the standard procedure for the assessment of the flour quality (Standard AFNOR V03-716, 2002), an important resource for French bakery industry (Roussel & Chiron, 2002). This procedure includes a protocol for the breadmaking process and provides an evaluation grid of the dough and the bread quality (Table 1). The evaluation grid encompasses a set of dough properties, defined in a glossary also including their rheological interpretation (Roussel, Chiron, Della Valle, & Ndiaye, 2010). It includes a rating scale of seven values, with the reference value for a standard French breadmaking process as central value in the scoring scale (Table 1). The experts consider that mixing encompasses two main operations: ingredient blending and kneading (Fig. 1). Flour specifications encompass physico-chemical specifications and parameters from the milling process. They determine the flour water absorption capacity, *wac*, which is required to predict the dough consistency after ingredient blending, in relation with the formulation specifications, i.e. the doses of raw materials and of functional ingredients. Then the kneading operation is described by four variables, thought to cover most of the conditions faced in French bakery. At the end of kneading, dough is described by six properties belonging to the evaluation grid (Table 1), plus the *cream colour* which the experts thought useful to add.

Two types of relation between these variables have been elicited from expert knowledge: (1) causal relations (Ndiaye et al., 2009) such as, for instance, "the higher the damaged starch, *ds*, the greater the water absorption capacity, *wac*" and (2) correlations, stemming from experience, such as "*wac* increases when protein content *pc* increases and remains slightly excessive when $pc > 11.5\%$". In this latter example, *pc* is beyond the standard value interval of [10.5, 11.5] (see Nomenclature). The relations between *ds* and *wac*, and *pc* and *wac*, as well as the way they are modelled in the system, are graphically represented in Fig. 2. These relations have been captured during interview sessions for all values of the variables, and they are represented in decision tables, an example of which is given in Table 2, and which are then modelled as qualitative functions.

Table 1
Scoring of the dough mixing operation according to the standard of the French breadmaking test and mapping of the result as symbols of the quantity space *Q*. *Stickiness* and *slackening* are the most critical properties for mixing and therefore are weighted by the highest coefficients for the calculation of the dough score at mixing. In the grey sections the values not belonging to the quantity space of the variable.

Expert evaluation scale	Corresponding value in Q	Smoothing aspect	Stickiness	Consistency	Extensibility	Elasticity	Slackening
very excessive	ve						
excessive	e						
slightly excessive	se		x		x		
normal	**n**	**x**		**x**		**x**	**x**
slightly insufficient	si						
insufficient	i						
very insufficient	vi						

The standard values are in bold.