FROM EXPERT KNOWLEDGE TO QUALITATIVE FUNCTIONS: APPLICATION TO THE MIXING PROCESS

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ABSTRACT
We present a procedure of knowledge representation based on a qualitative algebra, to predict the wheat flour dough behaviour from mixing settings. The procedure guarantees the consistency of the knowledge base and provides a concise and explicit representation of the knowledge. The qualitative model is implemented as a knowledge-based system (KBS) accessible and understandable by scientists and technologists in breadmaking. The KBS is a record of the domain knowledge, mainly know-how, and a tool to confront predictions of the dough condition with real observations. An example of such a confrontation about the wheat flour dough mixing process is shown; the results gives insight into ill-known relations between the process settings and the dough condition.

Keywords: qualitative modelling, know-how, breadmaking, expert knowledge.

1. INTRODUCTION

The general idea that domain know-how can do a lot for the production of scientific knowledge becomes more concrete, for example in the domain of knowledge management (Van de Ven and Johnson 2006) and agronomy (Girard and Navarette 2006). Indeed, in the domain of food industry, the management of production still relies on know-how, while scientific knowledge explains a part of the phenomena occurring during a process. Therefore know-how can help to point out the lack of knowledge with questions like why this practice fundamentally works or how can we improve it? Answering such interrogations will drive the production of an operational scientific and technical knowledge that in turn will support the improvement of practices.

The challenge is to elicit and represent the know-how so to make it accessible for any food scientists and technologists involved in production. As a matter of fact, the knowledge related to the implementation of food processes is partly tacit as shown by Nonaka and Takeuchi (1995) in their work on the bread making machine. Moreover know-how is valid in a given context of production, seldom defined or even known.

To address this issue we chose to work with a group of technologist experts and domain researchers to build a knowledge-based system (KBS) on a given topic in food science so to select operational knowledge with scientific consistency. To structure the knowledge of different sources we adopted a systemic approach. Both choices seem equally important to hand on the knowledge of the knowledge base to the different professional communities.

The domain of application is the French breadmaking. Breadmaking is a multistage processing chain, the management of which relies on professional know-how, without direct input from the large scientific literature available on wheat flour dough rheology and structure.

The KBS should ultimately predict the dough or bread condition from the inputs and processing conditions. At the moment, the modelling phase of the mixing process is over and two models were developed, the pre-mixing operation model (Kansou et al. 2008) and the texturing operation model (Ndiaye et al. 2009). The knowledge on the mixing process is mostly a domain know-how consistent with scientific principles. One of the first challenge of this work was the following:

- building an explicit representation of the expert knowledge and maintain the consistency of the KB when it is updated or refined. Indeed, because the KB ought to be a repository of knowledge about a given topic, it needs to be updated along with the advance of the domain knowledge.

In this article, we present a knowledge representation procedure that addresses this point through the building of a qualitative model of the expert reasoning for the mixing process.

In the background section we present features of the expert knowledge in breadmaking and the qualitative algebra, *Q*-algebra, which is the formalism developed to represent this knowledge. Then, we illustrate the knowledge representation procedure with an example taken from the qualitative model of the texturing operation, the second stage of the mixing process. Then we describe briefly the KBS about the mixing process and the result of the validation stage.

Finally we will present results from the confrontation of the KBS' predictions against real observations of the dough condition.

2. KNOWLEDGE AND TECHNOLOGICAL BACKGROUND

French breadmaking has long been a traditional activity relying on craftsman's manual skills. Today, part of the baker's work is automated and it is also an industrial activity, which demonstrates a good level of knowledge about the ingredients and the baking process. From a physico-chemical point of view, the successive stages of the breadmaking bring about an initially dispersed granular medium (flour) to become a visco-elastic homogeneous mass (mixed dough), aerated (after the fermentation) and finally fixed (after the baking) (Bloksma 1990). However the causal relations between the physico-chemical properties of the components and the sensory and nutritional characteristics of bread, according to the sequence of unit processes (mixing, proofing, laminating… cooking), remain ill known; so the development of scientific models of the whole process or even unit operations is still challenging.

Among the operations of breadmaking, mixing is crucial because it covers the formation of the dough, and yet one of the most ill-known stage of the process (Stauffer 2007). This motivates the building of a qualitative model of the mixing operation, to state what the know-how says about the relationship between the dough behaviour and the setting of mixing.

3. KNOWLEDGE IN BREADMAKING, HOW EXPERTS PREDICT THE DOUGH CONDITION

3.1. Descriptors and evaluation grid to assess dough condition

An important resource of this work is the standard procedure for the evaluation of the French breadmaking process (including ingredients quality) (NF V03-716, 2002). The procedure includes an evaluation grid of the dough and the bread (Tab. 1). This grid is now widely used in French baking technical centres and training institutes. After each step of the breadmaking process a trained baker describes the dough condition according to a set of sensory descriptors, which reflect important properties of the dough. Sensory descriptors are assessed following a scale of notation of 7 levels centred around the normal level considered as the reference value for a standard French bread. Assessment of a deficiency in a property ranges over 3 levels (very insufficient, insufficient, slightly insufficient) as well as the excess of a property (very excessive, excessive, slightly excessive). Some descriptors can only be assessed in excess or in insufficiency, for example a dough can be excessively sticky but never insufficiently sticky.

Table 1. Standard scoring of the dough mixing operation according to the standard of the French breadmaking process (NF V03-716, 2002)

The scale of expert	*Very insufficient*	*Insufficient*	*Slightly insufficient*	*Normal*	*Slightly excessive*	*Excessive*	*Very excessive*
Notation	1	4	7	10	7	4	1
MIXING							
SMOOTH ASPECT				x			
STICKINESS					x		
CONSISTANCY				x			
EXTENSIBILITY					x		
ELASTICITY				x			
STABILITY				x			

3.2. Type of expert knowledge

The domain expert knowledge is expressed first as simple rules "If-Then", which are punctual knowledge such as:

"If the protein content of the flour is high (>12%) then the dough consistency at the end of the first mixing will be excessively firm"

or

"If the protein content of the flour is high (>12%) and the water content of the dough slightly high then the dough consistency at the end of the first mixing will be normal"

In these examples the dough consistency is a sensory descriptor, whereas the protein and the dough water contents are measurements.

Besides this punctual knowledge, the expert knowledge consists also in functional relationships between two variables, called functional knowledge. This kind of knowledge is expressed with assertions such as "the more X, the more Y". For example:

"The higher the flour protein content the more the firmness of the dough"

and also

"The higher the dough water content the more the softness of the dough"

Note that these two functional knowledge are consistent with the two previous If-Then rules.

According to Dieng et al. (1995), the functional knowledge plays an important role in the expert reasoning. It results from the abstraction of a scientific knowledge, a physical law for example, or from the synthesis of many observations or trials. Such knowledge expresses the way a variable behaves along with another and therefore should be captured in the knowledge base. A classical rule-based representation is inadequate in this regard.

4. BACKGROUND

4.1. Qualitative algebra (Q, ≈, ⊕, ⊗)

This work is based on the *Q*-algebra defined in Ndiaye et al., (2009). Here are summarized the basic elements of the formalism:

- A quantities space (*Q*) of seven symbolic elements strictly ordered (vvl < vl < l < m < h < vh < vvh), as defined in Guerrin (1995), that maps exactly the scale of notation used by experts to assess the descriptors of the dough, and with {?} the indecision symbol;
- For measurements whose domain of value is the set of real numbers, elements of *Q* are representative of the absolute order of magnitude based on a partition of the real line:]-∞, x1],]x1, x2],]x2, x3],]x3, x4],]x4, x5],]x5, x6],]x6, +∞[. For observations, a symbolic scale of a maximum of seven elements is used. The interpretation of an observation depends on the context, for a sensory descriptor the scale of assessment is: very insufficient, insufficient, slightly insufficient, normal, slightly excessive, excessive, very excessive.
- A qualitative equality (≈ meaning “possibly equal to”). ≈ is reflexive, symmetrical, and intransitive in the general case:

$(x \approx y)_{def}$

$$\forall x \in Q, \exists y \in Q : x \approx y \Leftrightarrow \exists z : z \subseteq x \wedge z \subseteq y$$

- A qualitative addition (⊕), whose definition is given in tables 2. ⊕ is commutative, associative, admits m as a neutral element and admits the symmetrical element $(\forall x \in Q, \exists x' \in Q : x \oplus x' = x' \oplus x \approx \mathrm{m})$;
- A qualitative multiplication (⊗), whose definition is given in tables 2. ⊗ is commutative, associative, admits h as a neutral element, m as an absorbing element, does not admit a symmetrical element and is qualitatively distributive compared to ⊗;
- Two specific functions (⊤ and ⊥), whose definitions are given in table 3. ⊤ and ⊥ have the following property: ⊤(*x*) ⊕ ⊥(*x*) = *x*. Those two functions were introduced to represent non-linear evolution, such as saturation or initiation, up to or beyond a given threshold, respectively.

Operators and specific functions of the Q-algebra map the basic cognitive operations used by the experts to predict a dough condition. A complex reasoning is represented by a combination of these basics functions.

4.2. Modelling the breadmaking process

A breadmaking process is seen as a sequence of breadmaking operations. An operation is a transformation of the dough whose state is formally described by a set of state variable which represent the sensory descriptors (see section 3.1). Each operation accepts as input a set of state variable describing the dough resulting from the preceding operation, except the first one (pre-mixing) which transforms the ingredients into a dough. Each breadmaking operation is controlled by its control variables that capture the settings and adjustments of the equipments or the baker's actions.

Tables 2. Definition of the qualitative addition (⊕) and multiplication (⊗) in the *Q* ∪ {?} space (Ndiaye et al. 2009)

⊕	vvl	vl	l	m	h	vh	vvh	?
vvl	vvl	vvl	vvl	vvl	[vvl, vl]	[vvl, l]	?	?
vl	vvl	vvl	vvl	vl	l	m	[h, vvh]	?
l	vvl	vvl	vl	l	m	h	[vh, vvh]	?
m	vvl	vl	l	m	h	vh	vvh	?
h	[vvl, vl]	l	m	h	vh	vvh	vvh	?
vh	[vvl, l]	m	h	vh	vvh	vvh	vvh	?
vvh	?	[h, vvh]	[vh, vvh]	vvh	vvh	vvh	vvh	?
?	?	?	?	?	?	?	?	?

⊗	vvl	vl	l	m	h	vh	vvh	?
vvl	vvh	vvh	vvh	m	vvl	vvl	vvl	?
vl	vvh	vvh	vh	m	vl	vvl	vvl	?
l	vvh	vh	h	m	l	vl	vvl	?
m	m	m	m	m	m	m	m	m
h	vvl	vl	l	m	h	vh	vvh	?
vh	vvl	vvl	vl	m	vh	vvh	vvh	?
vvh	vvl	vvl	vvl	m	vvh	vvh	vvh	?

Table 3. Definition of specific functions ⊤ and ⊥ in *Q* ∪ {?} space

x	vvl	vl	l	m	h	vh	vvh	?
⊤(*x*)	vvl	vl	l	m	m	m	m	?
⊥(*x*)	m	m	m	m	h	vh	vvh	?

5. KNOWLEDGE REPRESENTATION PROCEDURE, FROM EXPERTS TO THE KNOWLEDGE BASE

To elicit the way variables influence each other, we asked a group of three experts (two technologists and one rheologist) to fill in decision tables, that are basically relationship matrices between the input variables and the state variables (output variables) of a given operation of the breadmaking process. Experts collaborate to provide consensual relationship matrices. Relationship matrices are translated in tables of quantities following the projection from the experts' scale to *Q*.

The relationship matrices collected so far, capture the influence of one qualitative variable on another, *x* influences *y*, or two variables on another, *x* and *y* influence *z*. Most of the influences have a q-algebraic expression of the type *y* = *f(x) or z* = *f(x,y)*, *f* being a qualitative function of the *Q*-algebra.

As an example of the knowledge representation procedure let us consider the prediction of the dough consistency at the end of the mixing operation, *Cons*. *Cons* is a state variable influenced by the dough self-heating *ΔT*, caused by viscous dissipation, the consistency at the beginning of the mixing, *Cbm*, and the temperature at the end of the mixing, *Tem*. They can be considered as control variables since the first two are tuned by an experienced baker whereas the third is actually a target temperature used by bakers to control the mixing process. Here is the corresponding influence graph (Fig. 1)

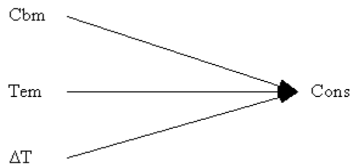


Figure 1. Influence graph of the prediction of the dough consistency at the end of mixing

Projection step

Measurements and observations used by experts to describe the mixing conditions are translated in quantities. This is done through a projection operation defined as follows:

$$Pr: I\!R \rightarrow Q \quad or \quad V \rightarrow Q$$

With *V* a vocabulary space representing the scale of assessment of a given observation. Tables 4 show the projection for the three control variables of the mixing operation in the quantities space *Q*.

Tables 4. Projection tables for control variables

Cbm Measurement (UF)	**Quantity (*w*)**
Cbm≤350	l
350<Cbm≤450	m
Cbm>450	h

Tem Measurement (°c)	**Quantity (*x*)**
Tem≤22	l
22<Tem≤25	m
Tem>25	h

ΔT Observation	**Quantity (z)**
low	l
medium	m
high	h

We note *w=Pr(Cbm), x=Pr(Tem), y=Pr(ΔT)* and $Cons_i$ the state variable *Cons* influenced by the variable *i*.

Relationship matrices and mapping as qualitative functions

Three relationship matrices (Tab. 5) define the individual influences of *w, x, z* on *Cons*. They are represented by the following qualitative functions:

$Cons_w \approx w$

$Cons_x \approx l \otimes \perp(x)$

$Cons_z \approx l \otimes z$

Tables 5. Individual influences of *w, x, z* on *Cons*

w	$Cons_w$
l	l
m	m
h	h

x	$Cons_x$
l	m
m	m
h	l

z	$Cons_z$
l	h
m	m
h	l

We also need to know how to combine the three individual influences to determine the global qualitative function for the prediction of *Cons*. This requires relationship matrices describing the combined influences. The two relationships matrices allowing the identification of the global qualitative function are presented in Tables 6.

Tables 6. Relationship matrices for control variables

$Cons_{wx}$		$Cons_x$	
		l	**m**
$Cons_w$	**l**	vl	l
	m	l	m
	h	m	h

$Cons$		$Cons_z$		
		l	**m**	**h**
$Cons_{wx}$	**vl**	vvl	vl	l
	l	vl	l	m
	m	l	m	h
	h	m	h	vh

The patterns of the tables 6 match with the qualitative addition ⊕ (Tab. 2), meaning that the way experts combine the influences of the control variables is additive. Here follows the representation as qualitative functions:

$Cons_{wx} \approx Cons_w \oplus Cons_x$

$Cons_{wx} \approx w \oplus l \otimes \perp(x)$

$Cons \approx Cons_{wx} \oplus Cons_z$

$Cons \approx w \oplus l \otimes \perp(x) \oplus l \otimes z$

The qualitative addition (⊕) represents a kind of reasoning that is recurrent in this work.

Final results of the qualitative calculus have to be interpreted in a vocabulary space to be handed on to domain experts and users. Formally, interpretation is the inverse operation of the projection. The table 7 presents the interpretation of the *Cons* values as observations of the dough consistency at the end of the mixing.

Table 7. Interpretation of the qualitative variable *Cons* as dough consistency at the end of mixing

	Interpretation	Meaning for the users
Cons	**Consistency end of mixing**	**Implication for the rest of the process**
vvl	very insufficient	Dough very liquid, hard to manipulate and to make up . Poor quality bread expected
vl	insufficient	Soft dough, significant deviation from the reference. Requires short proofing stage and soft moulding
l	slightly insufficient	Slightly soft dough. Requires short proofing stage and soft moulding
m	normal	Normal value for a standard breadmaking process
h	slightly excessive	Slightly firm dough. Can still lead to good quality bread
vh	excessive	Firm dough, requires a long proofing stage, can undergo hard moulding

6. RESULTS, QUALITATIVE MODEL OF THE MIXING OPERATIONS

6.1. Qualitative model of the texturing phase and implementation

The *Q*-algebra had been developed so that the set of rules, experts use to assess a property of a wheat flour dough or bread, can be represented by a qualitative function. The *Q*-algebra was used to model the states of the dough at the end of the two successive operations of mixing: (1) pre-mixing during which the components are homogenized into a dough and (2) texturing which performs dough aeration and gluten network formation. The state of the dough at the end of the pre-mixing can be described by its consistency; it is influenced by the characteristics of the ingredients (%flour, water, protein and pentosan content…). The state of the dough at the end of texturing is defined by the following 8 descriptors: smoothing velocity (SV), smooth aspect (SA), Extensibility (Ext), stickiness (Stic), Stability (Stab), Consistency (Cons), Elasticity (Elas) and Creamy Colour (CC). This state is influenced by the consistency at the end of the pre-mixing operation (w), by the target temperature at the end of mixing (x), by the mixer setting and geometry, namely the difference in linear velocity between the arm and bowl (y), and by the expected heat dissipated during texturing (z). The selection of these variables and the technical terms is based on a glossary defining dough quality and bread baking, written in French by the same research group, and available on the Web (Roussel et al. 2010).

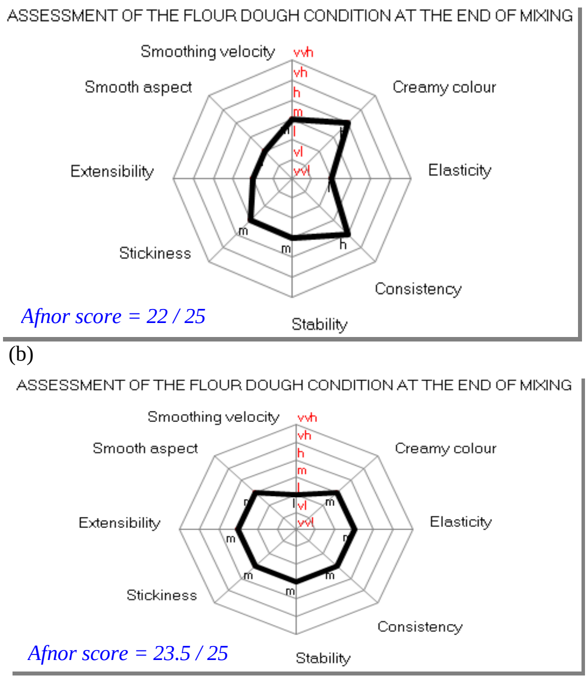
Figure 2 presents the set of qualitative functions forming the qualitative model of the texturing operation which allows to compute the state of a mixed dough from the initial consistency of the dough and from the operating conditions. There is a total of 8 functions, that is one function for each state variable of the model.

$$
\begin{aligned}
SV &\approx (1 \otimes w) \oplus \alpha(y,z) \\
SA &\approx \top((1 \otimes w) \oplus (1 \otimes \bot(x)) \oplus \top(z) \oplus (1 \otimes \bot(z))) \\
Ext &\approx (1 \otimes \bot(w)) \oplus (1 \otimes \bot(x)) \oplus \top(z) \oplus (1 \otimes \bot(z)) \\
Stic &\approx \bot((1 \otimes w) \oplus \bot(\bot(x) \oplus z)) \\
Stab &\approx \bot((1 \otimes w) \oplus \bot(x) \oplus z) \\
Cons &\approx w \oplus (1 \otimes \bot(x)) \oplus (1 \otimes z) \\
Elas &\approx (1 \otimes \bot(w)) \oplus x \oplus \top(z) \\
CC &\approx (1 \otimes z)
\end{aligned}
$$

Figure 2. Qualitative functions of dough state descriptors after mixing (Ndiaye et al. 2009)

Such models are implemented in the KBS using the *Qualis©* expert-system shell and the outputs are displayed to the users as plain text using the domain vocabulary, or as radar charts (Fig.3).

(a)



(b)

Figure 3. Examples of the KBS outputs: predictions of dough state at the end of texturing, starting from a standard consistency at the end of first mixing ($350 \leq w \leq 450$ UB), a standard target temperature ($22 \leq x \leq 25$ °C), an average difference of velocity y and a heat dissipation z (a) medium and (b) low. Scale ranges from vvh (very excessive) to vvl (very insufficient).

6.2. Validation

The validation of the knowledge base consists in comparing predictions given by experts with those of the KBS. When comparing distinct evaluations of the same food product, it is common, and experts do so, to take into account a sensibility level to distinguish acceptable divergences resulting from different sensibilities, from significant divergences (Allais et al. 2007). The threshold to do the distinction depends on the domain; in the case of breadmaking, the acceptable gap between two evaluations is of one level on the scoring scale of 7 levels (Tab. 1), e.g. very insufficient and insufficient or normal and slightly excessive are two acceptable divergences.

The qualitative model of the texturing operation covers 81 solutions that ought to be valid in a normal context of production; in other words, unreasonable mixing settings were not considered by the experts during the knowledge elicitation phase. The set of solutions was checked over exhaustively with the experts. Only one significant disagreement between the KBS and experts has been identified and reported in Ndiaye et al. (2009) giving a rate of 98.8% of acceptable predictions.

The divergence comes from the prediction of the smoothing velocity, for high self-heating and high difference of linear velocity. The experts found difficult to refine the knowledge about the difference of linear velocity which reflects an incomplete or tacit knowledge about the influence of this variable on the dough condition. As a matter of fact, the linear velocity difference influences only the smoothing velocity and, rather oddly, has no effect on the other state variables (Fig. 2). Experts predict the influence of the kneader based mostly on the dough self-heating, which reflects the amount of energy transmitted to the dough. They initially came up with the difference of linear velocity to integrate the influence of the kinematics of kneader on the dough properties; however, in a normal production context the influence of this variable turned out to be difficult to uncouple from the energy.

7. PREDICTIONS AGAINST EXPERIMENTS

We performed experiments to investigate the influence of the mixing setting on the dough condition. As said section 6.2, the incomplete integration of the difference of linear velocity reflects a lack of knowledge. Thus, experiments were designed in a research context to investigate the effect of extreme mixing conditions on the dough by combining the duration with the rotation speed of the mixer's arm. To reveal the influence of the difference of linear velocity, independently from the one of energy, mixing was conducted with a high-speed spiral kneader instead of the more commonly used low-speed oblique-axis kneader. Experimental design is presented in figure 4.

The two technologists involved in the project performed sensory measurements of the dough condition for the nine trials. Measurements were limited to the six sensory descriptors of the normalised assessment grid (Fig.1): Smooth Aspect (SA), Stickiness (Stic), Consistency end of the mixing (Cons), Extensibility (Ext), Elasticity (Elas), Stability (Stab). According to the model, the difference of linear velocity should not be involved in the prediction of these descriptors (Fig. 2).

The experiment settings were converted into input values for the four control variables in the KBS. The composition of the dough and the pre-mixing operation were standard and the same for the nine trials so that the consistency of the dough at the beginning of the mixing was always normal: Cbm ≈ m. Measurements of the dough temperature at the beginning and at the end of the mixing enabled to determine the dough selfheating as input in the KBS.

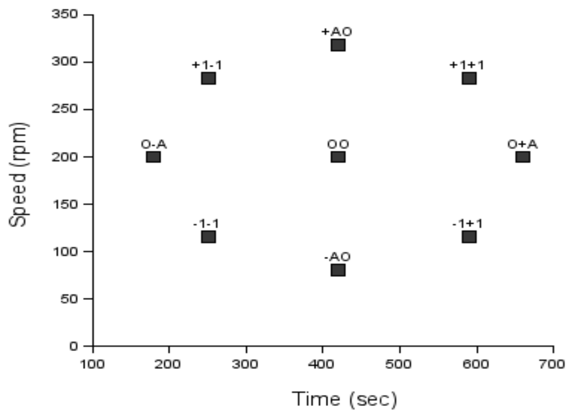


Figure 4. Repartition of the nine trials in the 2 dimension: space speed (rpm= rev per min) x texturing duration.

The results revealed three profiles of dough conditions corresponding to normal, low and high energy mixing (Fig. 5). The overall rate of acceptable predictions of the KBS is 88.9%, as illustrated Fig. 5a and b, predictions of the KBS for normal and low energy mixing is acceptable but significant disagreement comes from the case high speed and long duration (+1,+1) (Fig. 5c). Although four descriptors are correctly predicted, the smooth aspect is significantly better than the one predicted by the KBS and the dough elasticity is insufficient while the KBS predicts a slightly excessive elasticity.

This tends to show that out of a standard production context, the influence of the couple difference of linear speed and self-heating is incompletely captured by the model. It is likely that, for a long duration of mixing, the high speed mixing-arm impacts negatively the dough elasticity, while the smooth aspect remains correct. This is because spiral kneader applies much higher shear velocity to the dough than oblique-axis kneader do, resulting in a phenomenon of overmixing i.e. degradation of the dough protein network. Shear velocity is captured in the model by the difference of linear velocity, so better integration of this variable will extend the domain of validity of the KBS and incidentally the domain knowledge.

The physical relationship between the nature of the stress applied by the kneader and the dough properties is yet to be clarified (Stauffer 2007); the KBS was used as a support to point out the lack of knowledge; it also helped to perform well-focused experiments to characterise the relations between the dough behaviour and the mixing setting. The causes of the dough behaviour are now to be uncovered by the domain rheology.

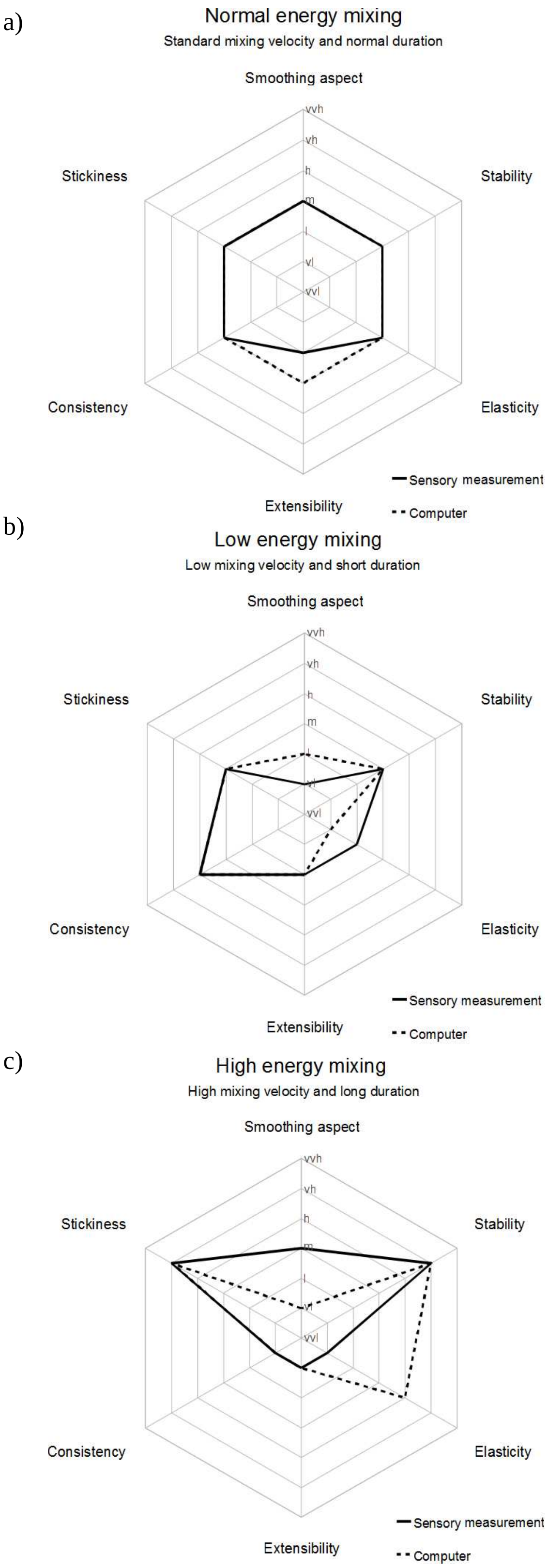


Figure 5. Confrontation between sensory measurements and predictions of the KBS for *a)* a standard mixing (trial 0,0), *b)* a low energy speed mixing (trial -1,-1) and *c)* high energy mixing (trial +1,+1).

8. DISCUSSION

We present a procedure to represent expert knowledge about breadmaking operations through qualitative functions. The value of each output variable is given by a unique function that integrates all the variables having an influence (e.g. Fig. 2); therefore, for each output variable it exists one and only one way to compute its value. This mode of representation, greatly facilitated by the use of the Q-Algebra, allows to avoid the problems of inconsistency of the knowledge base that can occur with other knowledge representations. To update the calculation method of one variable in the KB without jeopardizing the consistency of this last, it is necessary and sufficient to revise the algebraic expression of the concerned qualitative function.

The procedure, illustrated in section 5, reflects the majority of the situations we encountered so far. However two problems may occur: i/ a decision table given by an expert can only be represented by a complex qualitative function providing neither a concise expression of experts knowledge nor calculation benefits, in this case the decision table is used as such in the calculation process, ii/ the number of decision tables to be filled in is intractable for human experts because the number of combinations of variables is too large, in this case we incrementally prospect with the human experts the way they combine the variables. For instance, the prediction of the condition of the dough resulting from the pre-mixing operation requires the combination of 18 variables that gives about 10^{11} distinct combinations. To model this operation, we first implemented a simple qualitative addition of all the calculated variables reflecting the individual influences of the 18 input variables and then refined the model after each validation turn from the experts comments and corrections (Kansou et al. 2008). This knowledge elicitation technique takes advantage of the functional representation of the knowledge presented in this paper.

9. CONCLUSION

A KBS for the prediction of the mixed dough condition has been built on the basis of the human experts' know-how for technologists and scientists in the French breadmaking domain. A knowledge representation procedure based on a qualitative algebra to represent the knowledge through qualitative functions has been presented. With the procedure, the calculation of each variable used in the KBS is performed using a unique qualitative function, eliminating, *de facto*, the risk of having inconsistencies in the KB.

Finally, the elicitation and representation of the expert knowledge lead to the identification of lack of knowledge. Confrontation of the KBS predictions with the real observations of the dough condition is also a way to refine the knowledge and to reduce the lack of knowledge in the domain.

In the near future, the qualitative models should also be used to support decision by determining the best settings of the mixing operation to make a dough with the desired properties.

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