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The quality of steam-cooked rice bread is directly linked with the level of starch gelatinization and the fluidity of fermented dough

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A B S T R A C T

Ablo is a rice or maize-based steam-cooked bread-like product, very popular in Benin, Togo and Ghana. This study optimized the processing steps of rice ablo using response surface methodology. The effect of precooking (proportions of flour and water, duration), kneading (wheat level, duration), fermentation (yeast level, temperature, duration) conditions to dough (gelatinization level, fluidity, proofing) and ablo (ethanol content, pH, density, cooking expansion, firmness, alveolar structure) properties were studied. It was demonstrated that ablo texture can be controlled by the fluidity of the fermented dough. Fluid fermented dough (at least 0.5 cm/s) expands adequately during steam-cooking and results in a less dense ablo in line with commonly consumed ablo. The optimal dough fluidity comes from a low gelatinization level of the precooked dough (less than 20%) and an intense fermentation (high yeast dose and long fermentation). Surprisingly, dough proofing appears to have no effect on final ablo expansion.

1. Introduction

Over years, rice (*Oryza sativa*) acquired the status of staple food in West Africa. Even though the local production of rice is increasing in that part of the continent, the locally produced rice fails to compete with imported rice for direct cooking and consumption due to its variable raw and cooked grain quality (Tomlins et al., 2005). Processing into traditional food forms appears to be a good opportunity to add value to the locally produced rice. One of these traditional foods is ablo, a spongy, slightly acid, slightly sweet, and steam-cooked bread-like product. Ablo is very popular in Benin, Togo and Ghana. It is produced traditionally from maize in a four-step processing scheme: i) precooking of a dehulled maize flour, ii) kneading of a mixture of the precooked dough, raw maize flour, baker's yeast, salt, sugar, wheat flour and water, iii) fermentation of kneaded dough for 3–4 h, and iv) steam-cooking of fermented dough (Nago and Hounhouigan, 1994). Nowadays, ablo processors are gradually replacing the dehulled maize with imported milled rice. This practice simplifies the tedious dehulling step required when maize is used in ablo making (Nout et al., 2003). Dossou et al. (2011) described the ablo making technology, and Agro et al. (2014) proposed optimized fermentation conditions while the effect of the other unit operations has not yet been explored.

Optimizing ablo making could be inspired by lessons learnt from unconventional bread and pasta research. Gluten is responsible for the development of a viscoelastic network that renders bread or pasta dough elastic, extensible thus enables the retention of gas in wheat-based bread (Demirkesen et al., 2010, 2014; Sivaramakrishnan et al., 2004) and keeps the shape of pasta during drying and cooking (Mestres et al., 1993). To compensate the low gluten content in unconventional bread and pasta processing, partial starch gelatinization is often performed, as for ablo processing; gelatinized starch indeed acts as thickeners and improve dough viscoelasticity (Defloor et al., 1991; Onyango et al., 2010). Nevertheless, high gelatinization levels do not allow gas cell

Abbreviations: $rp_{precook}$, proportion of rice flour used at precooking step; $wp_{precook}$, proportion of total water used for precooking; $d_{precook}$, duration of precooking; GL, starch gelatinization level; wp_{knead}, proportion of total water used during kneading step; $dose_{wheat}$, amount of wheat flour added; wp_{knead}, proportion of total water used during kneading step; $dose_{yeast}$, amount of yeast added at fermentation step; t_{ferm}, fermentation temperature; d_{ferm}, duration of fermentation; cook-exp., dough expansion during steam-cooking.

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expansion in dough and is detrimental to bread quality (Onyango et al., 2010).

In this context, and targeting the development of a process for preparing a bread-like product (ablo) with local rice instead of imported rice and wheat flour, this paper evaluated the effects of the three main unit operations on intermediary and final products. It was hypothesized that: (a), precooking and gelatinization levels could directly affect the properties of precooked dough and ablo; (b) during kneading the amount of wheat flour and water added could impact gas production and (c) fermentation could directly influence dough proofing but also ablo quality (firmness, density, acidity).

2. Material and methods

2.1. Processing ingredients

The imported Thai rice is commonly used by the majority of ablo processors to deliver a traditional ablo with a low density (0.6–0.7 cm^3). This rice was used for the production of traditional ablo for follow-up studies. It was characterized by a high amylose content (22.7 ± 0.9%) and a relatively high gelatinization temperature (75.0 ± 1.7 °C). IR841 (amylose content, 18.3% ± 0.4%; gelatinization temperature, 62.5 ± 1.5 °C), a rice variety cultivated in Ouémé valley, Benin, and milled by ESOP Dangbo, Ouémé, Benin, was used in the optimization studies. This variety is widely produced and highly available in the country. It is characterized by a high brokens' rate after milling (73.1% ± 3.3%) and a high chalkiness (10.0 ± 2.3). Wheat flour (*type 45, Belle France*), refined sugar from natural cane, regular salt and baker's yeast powder (*saf-instant, S. I. Lesaffre, France*) were purchased from Dantokpa market, Cotonou, Benin.

2.2. Characterization of traditional ablo

Three experienced traditional ablo processors were followed during ablo making. During these follow-up studies, samples were analyzed at dough level (for proofing during fermentation and expansion during steam-cooking) and at ablo level (for acidity, density, and firmness). The measured characteristics of traditional ablo were reported by the processor to characterize ablo quality. They were used as references for defining optimal processing conditions after experimentation.

2.3. Experimental designs and sample collection

The most important factors and experimental domains were defined according with the practices of traditional ablo processors. Three experimental designs were used to estimate the individual effects of the key unit operations (precooking, kneading and fermentation) of ablo making on dough and ablo characteristics. The number of observations for precooking, kneading and fermentation experiments were 15, 10 and 16, respectively. For each experiment, the observations were collected randomly (Table 1).

In the precooking experiment, factors and experimental domains were the proportion of precooked rice flour ($rp_{precook}$, 25–50% of total rice flour), proportion of total water volume used at the precooking step ($wp_{precook}$, 40–90% of total water) and precooking duration ($d_{precook}$, 0 min, means that boiling water is added to the flour without additional heating, whereas 5–10 min means that the mixture was heated, after addition of boiling water, for 5 and 10 min, respectively). *Ablo* was prepared following the flowchart Fig. 1. For each trial, precooking was performed as follows. $wp_{precook}$ was added in two separate steps to rice flour: a first portion, kept at room temperature (27–30 °C), was mixed with $rp_{precook}$. Then, the second portion was boiled (95–98 °C) and poured onto the previous mixture. The resulting mixture was cooked during $d_{precook}$ and cooled down for 30 min. The precooked dough was then kneaded (using a *Masterchef gourmet mixer* set at speed 1 for 12 min) with remaining rice flour and ingredients such as salt (20 g), water (1260 mL minus volume of water used for precooking), wheat flour (170g) and baker's yeast (4 g). The kneaded dough was fermented at 30 °C for three hours, sweetened (with 30g of sugar), shaped and steam-cooked during 13 min. The ensuing optimal precooking conditions were used in the kneading experiment.

In the kneading experiment, factors and experimental domains were amount of wheat flour added ($dose_{wheat}$, 71–269 g wheat flour/kg of rice flour) and water proportion used at kneading step (wp_{knead}, 12.6–35% of total water). Ablo was prepared following the flowsheet Fig. 1 For each trial, 378 g of water was boiled and poured in 250 g of rice flour previously mixed with 378 g of water, then homogenized and cooled down for 30 min. The precooked dough was kneaded together with the remaining rice flour 750 g, the relevant wheat flour ($dose_{wheat}$), water (wp_{knead}), baker's yeast (4 g) and salt (20 g) on *masterchef gourmet mixer* during 12 min on speed 1. Then, the kneaded dough was fermented at 30 °C for three hours, sweetened (30 g) and wetted (1260 - 756 g − water used during kneading), shaped and steam-cooked for 13 min. Optimal precooking conditions are associated with the ensuing optimal kneading conditions for the fermentation experiment.

In the fermentation experiment, factors and experimental domains were fermentation temperature (t_{ferm}, 26.6–33.4 °C) and fermentation duration (d_{ferm}, 0.64–7.36 h) and amount of yeast ($dose_{yeast}$, 0.31–6.19 g/kg of rice flour). For each trial (Fig. 1), 378 g of water was boiled and poured in 250 g of rice flour previously mixed with the other 378 g of water, then homogenized and cooled down for 30min. One hundred and seventy g of wheat flour, 20 g of salt and $dose_{yeast}$ were then added to the optimized precooked dough and kneaded using 370 mL distilled water with *masterchef gourmet mixer* for 12 min. The optimized mixed dough mixed with 134 mL of water and immediately released to ferment at t_{ferm} (°C) for d_{ferm} (h). The fermented dough was sweetened (with 30 g of sugar), shaped and steam-cooked for 13 min.

2.4. Response quantification methods

2.4.1. Level of starch gelatinization

The enthalpy change of gelatinization was measured by Differential Scanning Calorimetry (DSC 8500, Perkin Elmer) according to Mestres et al. (2011) on native flour (ΔH_{native}, J/g) and precooked freeze-dried dough (ΔH_{dough}, J/g) samples. The level of starch gelatinization in pre-cooked dough ($GL_{precook}$, expressed in %) was calculated as follows:

$$GL_{precook}\,(\%) = [(\Delta H_{native} - \Delta H_{dough})\,{}^{*}100] \,/\, \Delta H_{native}$$

The level of starch gelatinization (GL, %) in the fermented dough was calculated from $GL_{precook}$ value and the relative proportion of precooked rice flour ($rp_{precook}$) in the fermented dough:

$$GL\,(\%) = GL_{precook} \,{}^{*}\, rp_{precook}$$

2.4.2. Fermented dough fluidity

The fluidity of fermented dough was determined using the Bostwick consistometer as reported by Bookwalter et al. (1968) and Vieu et al. (2001). The flowing distance of the dough (d, cm) was recorded after 30s and the value divided by 30 to calculate the

Table 1
Experiment design and variable combinations.

Non-conventional design for precooking optimization*						Central Composite design for kneading optimization				Central Composite design for fermentation optimization					
Level codes			Factor levels			Level codes		Factors levels		Level codes			Level codes		
$rp_{precook}$	$wp_{precook}$	$d_{precook}$	$rp_{precook}$ (%)	$wp_{precook}$ (%)	$d_{precook}$ (min)	$dose_{wheat}$	wp_{knead}	$dose_{wheat}$ (g/kg)	wp_{knead} (%)	t_{ferm}	d_{ferm}	$dose_{yeast}$	t_{ferm} (°C)	d_{ferm} (°C)	$dose_{yeast}$ (g/kg)
1	0	−1	50.0	65	0	−1	−1	100	15.9	−1	1	−1	28.0	6.0	1.5
0	1	1	33.3	90	10	1	−1	240	15.9	−1	−1	1	28.0	2.0	5.0
0	0	0	33.3	65	5	-δ	0	71	23.8	−1	−1	−1	28.0	2.0	1.5
0	−1	−1	33.3	40	0	0	0	170	23.8	-δ	0	0	26.6	4.0	3.25
0	0	0	33.3	65	5	−1	1	100	31.7	+δ	0	0	33.4	4.0	3.25
−1	0	1	25.0	65	10	+δ	0	269	23.8	0	0	+δ	30.0	4.0	6.19
−1	1	0	25.0	90	5	1	1	240	31.7	0	0	0	30.0	4.0	3.25
0	−1	1	33.3	40	10	0	-δ	170	12.6	0	0	0	30.0	4.0	3.25
0	0	0	33.3	65	5	0	+δ	170	35.0	0	+δ	0	30.0	7.4	3.25
0	1	−1	33.3	90	0	0	0	170	23.8	1	1	−1	32.0	6.0	1.5
−1	−1	0	25.0	40	5					0	-δ	0	30.0	0.6	3.25
1	1	0	50.0	90	5					0	0	-δ	30.0	4.0	0.31
−1	0	−1	25.0	65	0					1	1	1	32.0	6.0	5.0
1	−1	0	50.0	40	5					1	−1	1	32.0	2.0	5.0
1	0	1	50.0	65	10					1	−1	−1	32.0	2.0	1.5
										−1	1	1	28.0	6.0	5.0

-δ and +δ, axial points characterizing central composite design; −1 and +1, minimal and maximal points; 0, central point.
*Central composite design (CCD) was used to estimate the individual effects of kneading and fermentation of ablo making on dough and ablo characteristics. Box behnken design could be preferred to CCD for precooking optimization due to the lack of axial point -δ. $d_{precook}$ (level −1) = 0 min implies that -δ would be a negative precooking duration which could not be implemented. In addition, the majority of traditional ablo makers practice rp_{prcook} = 33.3% with a minimum and a maximum of 25 and 50% respectively. In order for the experiment to approach the reality, rp_{prcook} = 33.3% was included in the experimental design as central value instead of 37.5% the mean value of the experimental domain. The Box-Behnken design was therefore used to generate the 15 precooking optimization experiments and a non-conventional experimental plan.

fluidity.

2.4.3. pH and ethanol content of fermented dough

The pH of 10 g of fermented dough was measured as described by Nout et al. (1989) modified by Hounhouigan et al. (1993).

The ethanol content of fermented dough was determined by HPLC as described by Michodjèhoun-Mestres et al. (2005).

2.4.4. Fermented dough proofing

The proofing of fermented dough was measured using a 120 mL glass growth gauge graduated from 1 to 7 cm. Twenty-five g of ablo dough corresponding to the first graduation ($V_i = 1$) was introduced in the gauge. A light plastic disc lying on the dough was raised by the dough according with its proofing level (Roussel and Chiron, 2002). At the end of the fermentation, the final level (V_f) of dough was recorded and the proofing (expressed in %) was calculated:

$$\text{Dough proofing } (\%) = [(V_f - V_i) * 100] / V_i$$

2.4.5. Dough expansion during steam-cooking and ablo density

The volume of fermented dough to-be-cooked (V_{dough}) and the final volume of ablo (V_{ablo}) after steam-cooking were measured as described by Nishita et al. (1976) using fonio seeds instead of rapeseed. Expansion of the fermented dough during cooking ($cook_{exp}$) was assessed as follows:

$$Cook_{exp} (\%) = [(V_{ablo} - V_{dough}) * 100] / V_{dough}$$

V_{dough} was calculated as follows: $V_{dough} = V_{sp} * w$ with w the weight of the shaped dough and V_{sp}, the specific volume ($cm^3.g^{-1}$) of ablo dough. The specific volume was determined as follows: A 100 mL test-tube was filled with ablo dough and weighed. The specific volume was given by $V_{sp} = [100/(W - W_0)]$; where W_0 is the weight of empty test-tub and W the weight of test-tub after being filled with ablo dough. Afterwards, the ablo itself was weighed (W_{ablo}) and density was calculated: W_{ablo}/V_{ablo}.

2.4.6. Ablo firmness

Right after steam-cooking, four cakes of ablo were immediately kept at 45 °C for 1 h. Firmness was assessed using a Texture Analyser (Stevens-LFRA texture analyzer, Harlow. U.K.) equipped with a conical probe. The resistance of ablo to probe penetration (expressed in gram) over 5 mm at a speed of 1 mm/s was measured four times and averaged.

2.4.7. Number and size of ablo gas cells

The number and size of ablo gas cells were determined by image analysis. Ablo was sliced and an image of each slice was acquired with Desk Scanner (Hewlett Packard, USA) under 600 dots per inch (dpi) resolution. Brightness, contrast and image dimensions were adjusted using Paint.net v4 software (Microsoft, 2007). Thresholds between 230 and 250 grey levels was applied on adjusted image and number and size of objects (gas cells) were measured using SigmaScan pro v5 software (SPSS Inc.). Three types of alveolar structure were defined: Fine structure (size < 10 mm); intermediate structure (10 ≤ size < 53 mm) and gross structure (size ≥ 53 mm).

2.5. Statistical analysis

Experiment designs were defined and data analyzed using MINITAB software package (MINITAB Inc. Release 16 for windows). All measurements were done in duplicates and the mean values used for statistical analysis. The measured responses were analyzed through multiple regression analysis. The significance of the terms in the model was tested by an analysis of variance (ANOVA) using Statistica 12.0 (Statsoft, Tulsa, USA) and 3D response surfaces were plotted.

The optimal responses of dough (proofing during fermentation and expansion during steam-cooking) and ablo quality (density and firmness) were found out using the desirability function approach

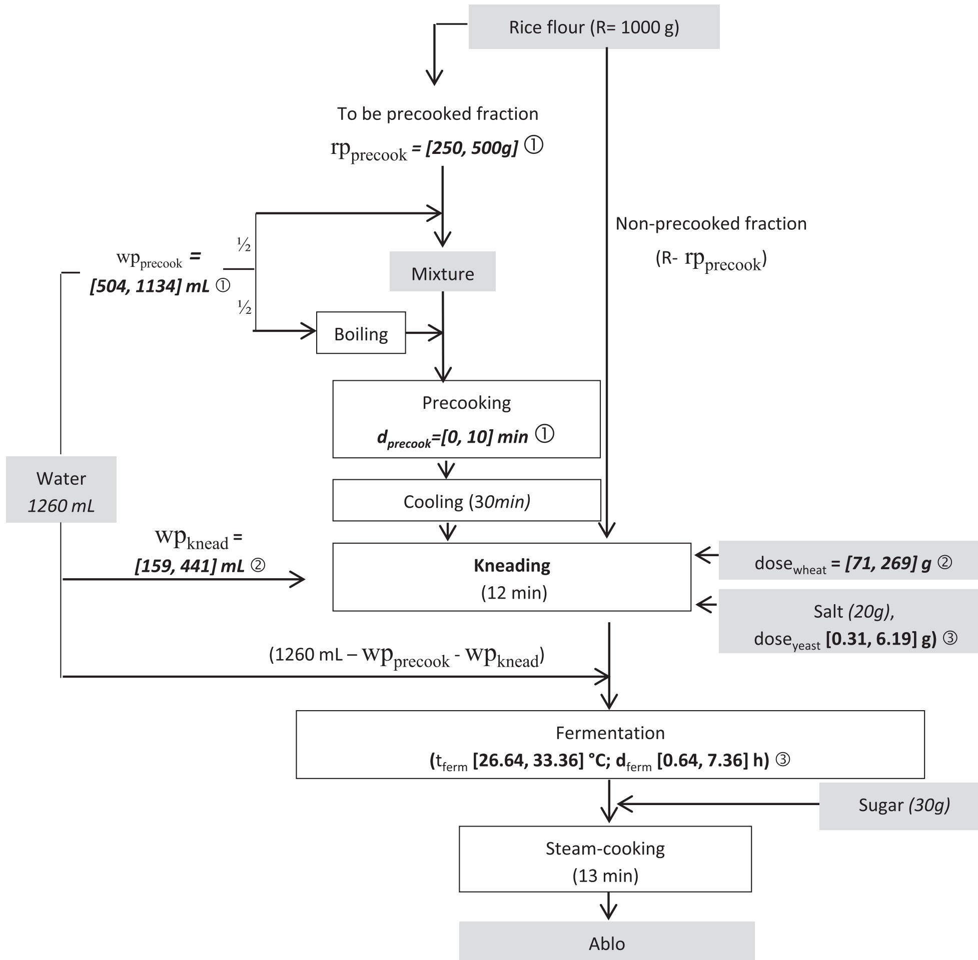

Fig. 1. Flowchart of Ablo processing for precooking ①, kneading ② and fermentation ③ optimization: $rp_{precook}$ is the proportion of precooked rice flour; $wp_{precook}$ is the proportion of total water volume used at the precooking step; $d_{precook}$ is the precooking duration; $dose_{wheat}$ is the amount of wheat flour added at kneading step; wp_{knead} is the water proportion used at kneading step; t_{ferm} is fermentation temperature; d_{ferm} is the fermentation duration; and $dose_{yeast}$ is the amount of yeast used at fermentation step.

associated with the response surface methodology.

A multiple factorial analysis (MFA) was also performed using XLSTAT 2015 to establish relationship between dough properties, ablo quality and processing parameters (precooking, kneading and fermentation conditions). Three groups (process, intermediate and ablo quality) of variables were defined: the process group including precooking conditions (rice flour proportion, water volume used and duration), kneading conditions (wheat level and water proportion) and fermentation conditions (Temperature, duration and yeast level); the intermediate group is related to dough characteristics during processing including gelatinization level, acidity and ethanol content of fermented dough, fermented dough fluidity, dough proofing level, and dough expansion during steaming; the ablo quality group includes density, firmness and alveolar structure.

3. Results and discussion

The characteristics of ablo, as commonly consumed, are presented below. Proofing of the fermented dough ranges from 15 to 40% whereas dough expansion varies from 50 to 65% during steam-cooking. The resulting traditional ablo has an acid pH (4.5–5.0), a low density (0.6–0.7 cm^3) and a firmness ranging between 78 and 108 g.

Table 2 presents the data range in the characteristics of doughs and ablo for the three optimization experiments. The fermented dough flew (fluidity varies from 0.2 to 0.6 cm/s), in any case, due to the low level of wheat and gluten. The final product, ablo, was characterized by an acid pH (4.7–5.4) in the same range as the one measured by Dossou et al. (2011) and Agro et al. (2014), namely 4.4–5.3. Great variation in the expansion of the dough was observed during steaming (from 2.5 to 98%) and the density of the resulting ablo ranged from 0.66 to 1.19 $g.cm^3$. This density is 1-2-fold of rye-based bread (0.55 $g.cm^{-3}$) and 4-7 fold the density (0.16 $g.cm^{-3}$) of common French "baguette" (Saulnier et al., 2014).

3.1. *Effect of precooking and kneading conditions on dough behavior and ablo quality*

Suppl. 1 presents the statistical models for predicting dough properties during processing and the quality of ablo. These models explain more than 60% of the variability existing in raw data (R^2, 0.62–0.99). Precooking parameters ($rp_{precook}$ and $d_{precook}$) influenced dough properties significantly during processing (GL and $Cook_{exp}$) and ablo quality (density and firmness) whereas $wp_{precook}$ affected only GL and density. As expected, an increase of $rp_{precook}$ or $wp_{precook}$ or $d_{precook}$ resulted in a significant increase in the gelatinization level of the fermented dough (Fig. 2.1a) and ablo density (Fig. 2.1b). When precooking is performed by just mixing hot water with rice flour, the temperature of the dough reaches a maximum

Table 2
Data range for the characteristics of precooked dough, fermented dough and Ablo during the three experiments

Characteristics per type of product	Precooked dough	Fermented dough		Ablo									
	GL (%)	Proofing (%)	Fludity (cm/s)	pH	Ethanol (g/100g)	Cook-exp (%)	Density ($g.cm^{-3}$)	Firmness (g)	Fine structure	Intermediate structure	Gross structure	Total number of alveolus
Minimum value	11.4	54.2	0.19	4.7	0.01	2.5	0.66	91	21	14	2	64
Maximum value	46.2	125.8	0.60	5.4	0.12	98	1.19	218.3	105	75	26	190

of 66 °C, which is close to the gelatinization temperature of the raw material (63 °C) and GL values are low (11–28%); these points are plotted below the surface response on Fig. 2.1a. The precooking conditions did not clearly impact the proofing of dough during fermentation (Suppl. 1) and the firmness, but low $d_{precook}$ led to higher dough expansion during cooking. Finally, higher values for the parameters of the precooking conditions contributed to the production of dense ablo (Fig. 2.1b). Knowing that consumers prefer a fluffy (less dense) ablo, mild precooking conditions will be preferable. Optimal pre-cooking was thus performed for the rest of the study by mixing boiling water (60% of total water) with 25% of the total rice flour.

Suppl. 2 shows the regression coefficients for the kneading experiment and Fig. 2.1 (c and d) illustrates these relations. High $dose_{wheat}$ favoured proofing during fermentation and expansion during cooking resulting in a less dense (fluffy) but firm ablo. Such a product is in line with consumer preference for a very light product. The proportion of water used during kneading has no direct significant effect on dough and ablo properties, but it correlates negatively with $dose_{wheat}$; lower wp_{knead} is thus preferred when $dose_{wheat}$ is high. Optimal kneading requires the use of 170 g of wheat flour per kg of total rice flour and 29.4% of total water used in ablo making.

A Multiple Factorial Analysis (MFA) was performed to evaluate the multifactorial relationships between precooking and kneading experimental conditions (first set of variables), dough properties (second set of variables) and ablo quality (third set of variables). The two first dimensions of the MFA (Fig. 3a) aggregated 52.7% of total variance. Fig. 3a shows, on the one hand, that i) $rp_{precook}$ and $d_{precook}$ (experimental variables), ii) GL and $cook_{exp}$ of the dough, iii) density and firmness of ablo are correlated with MFA axis 1 (F1) and between themselves. Longer precooking ($d_{precook}$) of a higher proportion of the flour ($rp_{precook}$) resulted to an increase in GL which limited dough expansion during cooking (Fig. 4a) followed by the production of a dense ablo (Fig. 4b). Starch gelatinization indeed largely explains the dough/crumb transition during bread baking (Rouillé et al., 2010) thus contributing to stopping loaf expansion. Moreover, according with previously interviewed ablo processors, the level of control over the precooking step determines dough behaviour during steam-cooking. Starch gelatinization level of the dough has dual opposite effects during unconventional bread making. Pre-gelatinized starch provides cohesiveness, viscosity and traps air bubbles in the gluten-free dough (Hugo et al., 1997; Olatunji et al., 1992), whereas highly gelatinized starch forms a stiff, inelastic dough that does not permit expansion of the gas cells (Onyango et al., 2010). Our results indeed show that the optimum level of gelatinization should be low (less than 20%, Fig. 4b) in the fermented dough to ensure bubble retention and loaf expansion during steaming.

On the other hand, i) $dose_{wheat}$, ii) dough proofing and iii) fine alveolar structure of ablo are related strongly to MFA axis 2 (F2). During fermentation, the higher the amount of wheat added, the more important is the retention of gas during proofing. Indeed, gluten from wheat flour is largely recognized as the gas holding agent during dough fermentation and thereby, increases dough proofing and preventing dough collapse (Demirkesen et al., 2014; Sivaramakrishnan et al., 2004).

It should be noted that proofing on one side and cooking expansion and ablo density on the other side are plotted on different axes which means that they are independent. Cooking expansion and density were indeed not correlated with proofing values.

3.2. Effect of fermentation conditions on dough behavior and ablo quality

Suppl. 3 shows the regression coefficients associated with the fermentation experiment and response surfaces are presented in Fig. 2.2. Higher d_{ferm} and $dose_{yeast}$ increased significantly dough fluidity, ethanol content and dough expansion during cooking whereas pH of fermented dough dropped significantly. Specifically, dough fluidity drastically increased when the fermentation was more intense (Fig. 2.2a). It can be concluded that gelatinized starch present in the dough has been hydrolyzed during fermentation hence thinning the dough. Finally, D_{ferm} reduced significantly the density, firmness and fine alveolar structure of ablo (Fig. 2.2 b-d). Optimal fermentation conditions, that give the best quality of ablo (lowest density and firmness), are as follows: addition of 6 g of baker's yeast par kg of rice flour and fermentation at 31 °C for 5 h.

The first two axes of the MFA performed on fermentation experimental results explained 62.2% of total variance (Fig. 3b). The first axis shows that fermentation duration controls fluidity, pH and ethanol content of the fermented dough, dough expansion during cooking as well as firmness and density of ablo. When the fermentation process was prolonged, pH, ethanol content and fluidity of the dough increase. Indeed, starch granule hydrolysis by yeasts induces an increase of ethanol and carbon dioxide contents. This carbon dioxide is partly responsible for pH lowering as it will be transformed into carbonic acid by diffusing in dough liquid phase (El Mehdi et al., 2003). The reduction of pH could also be due to bacterial growth as the substrate was not sterile before inoculation with baker' yeast (Dossou et al., 2011) and lactic acid bacteria can grow during dough fermentation and produce lactic acid (Agro et al., 2014). The level of fluidity of the fermented dough may then play a key function in dough expansion during steaming as a strong correlation was evidenced between dough fluidity and dough cooking expansion (Fig 4c); a fluidity higher than 0.5 cm/s seems necessary to get a maximum loaf expansion during steaming. It produces in addition ablo with lower firmness. Rheology of the dough indeed plays a fundamental role on its ability to support the deformation induced by the gas produced within its structure (Demirkesen et al., 2010; Sivaramakrishnan et al., 2004). Onyango et al. (2010) thus added amylase in non-wheat dough to decrease the firmness of the dough and of the crumb.

The second axis (Fig. 3b, axis 2, F2) revealed that an increase in temperature during fermentation lead to an ablo with a high number of gas cells. Indeed, the high temperatures could stimulate a better microbial activity leading to a better gas production. This

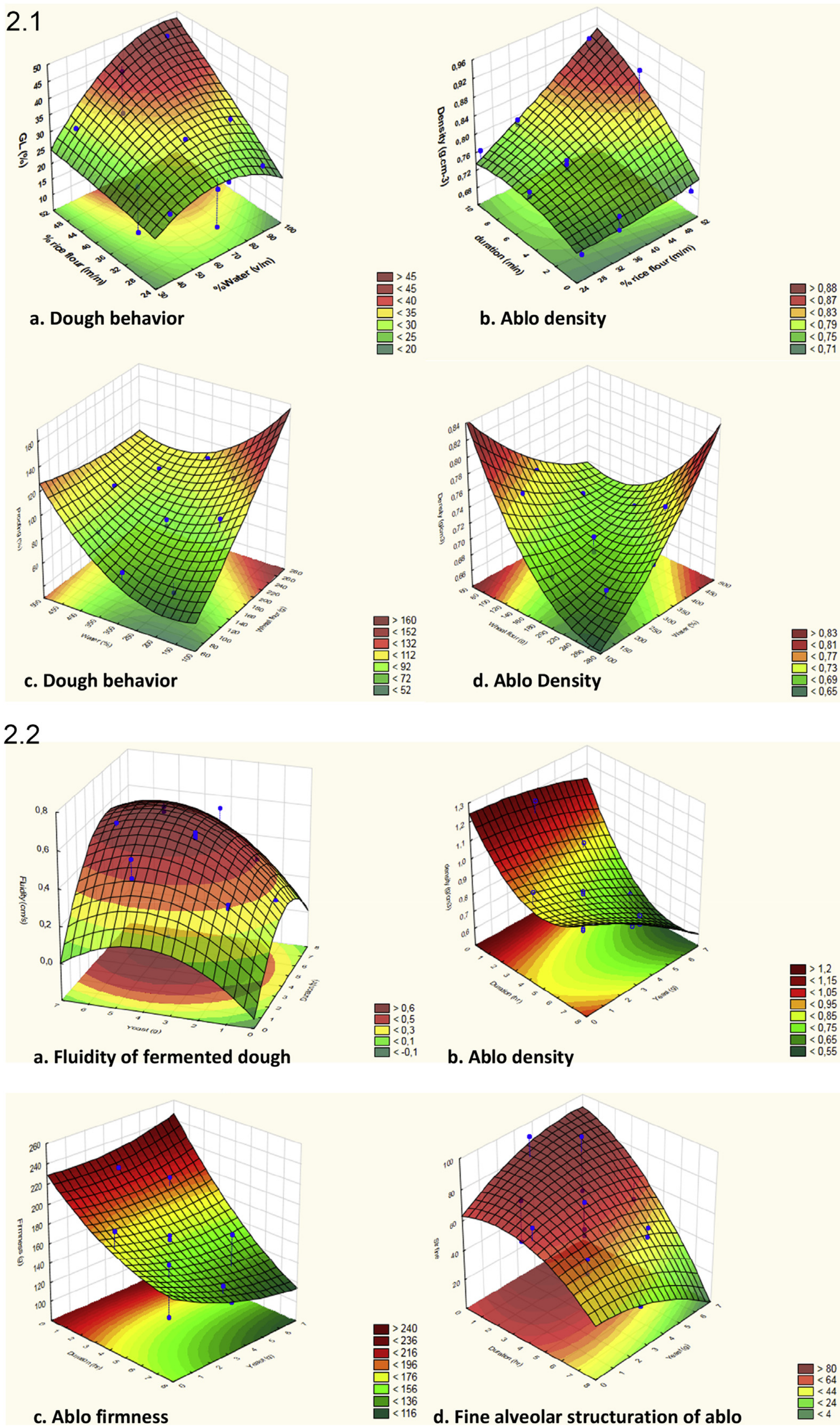

Fig. 2. 2.1. Response surfaces plots showing the changes in dough behavior and Ablo quality under precooking conditions (a, b), kneading conditions (c, d). **2.2**. Response surfaces plots showing the changes in dough behaviors and Ablo quality under fermentation conditions (a, b, c, d).

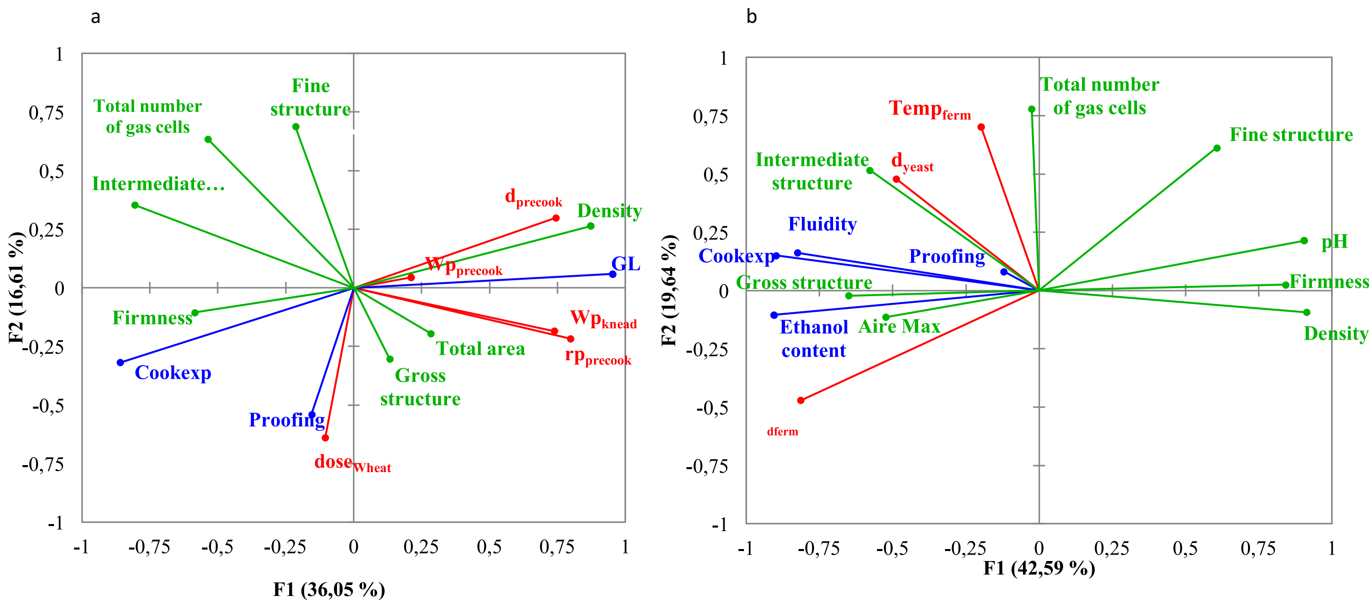

Fig. 3. Projection of process conditions (identified in red), intermediate variables (identified in blue) and Ablo quality (identified in green) on two first axes of MFA for precooking and kneading experiment (a) and fermentation experiment (b). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

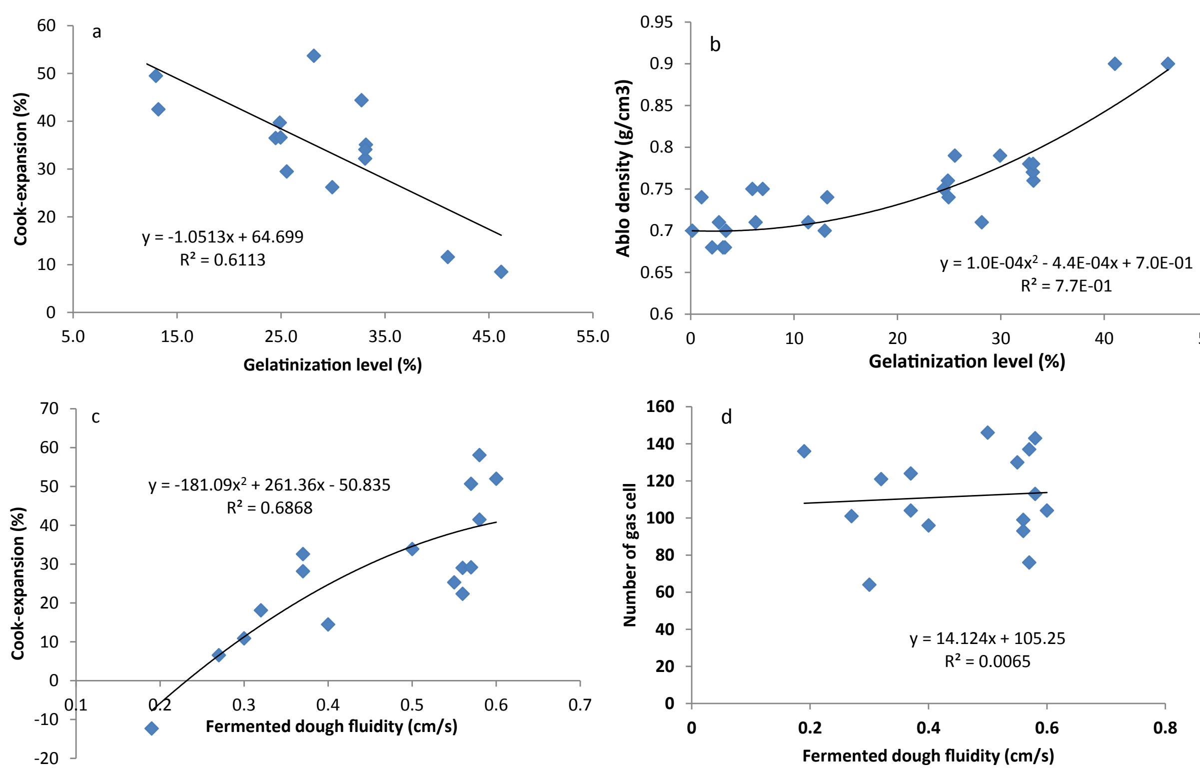

Fig. 4. Scatter plot of gelatinization level and cook-expansion (a), gelatinization level and Ablo density (b), dough fluidity and cook-expansion (c), dough fluidity and number of alveolus in ablo (d).

case is comparable with the positive correlation found between fermentation temperature, amount of yeast added, number of alveolus and fine alveolar structure of bread crumb previously established by Borzani (2004); Tlapale-Valdivia et al. (2010) and Demirkesen et al. (2014).

Besides, proofing of fermented dough is neither significantly correlated with axis 1, nor with axis 2. Such result means that no matter how the dough generates bubbles and withstands bubbles loss during fermentation, such process does not influence the behaviour of the dough during cooking as well as ablo quality. This observation could be linked to the important gas loss that results from dough handling after fermentation: fermented dough is indeed mixed with sugar before shaping in baking tins. The origin of the expansion of ablo is indeed largely different of what is observed in traditional bread process for which the final alveolar structure of the crumb largely depends on that of the dough (Saulnier et al., 2014).

4. Conclusion

The optimal conditions for preparing ablo from IR841 rice variety are summarized in suppl. 4. A low level of pre-cooking and a long fermentation give a fluid batter and favoured the expansion during cooking resulting in an ablo with low density (0.66 g cm^{-3}). This density is quite close to the one of rye-based bread (0.55 g cm^{-3}) and 4-fold the density (0.16 g cm^{-3}) of common French “baguette” (Saulnier et al., 2014). We thus demonstrated the possibility to prepare an ablo with similar characteristics with the traditional one, but made with a local rice while processors prefer to use imported rice which have higher amylose and gelatinization temperature. Therefore, further work should focus on the effect of the rice cultivar on ablo quality.

The fluidity of the dough can be measured by a very simple method, and has a great impact on dough expansion during cooking. Precooking (duration) and fermentation (dose of yeast used and duration of fermentation) conditions can be used to control the fluidity. This relationship begins to fill the existing gap of knowledge between dough property and bread quality for unconventional bread research. More research should be performed on this respect. Furthermore, the usefulness of and the amount of wheat flour in determining the final properties of ablo deserve in-depth research as improving dough proofing did surprisingly not affect the final expansion and texture of ablo.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jcs.2018.01.006.

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