Millet-Wheat Mixed Breads: Impact of Sour Dough Addition on the Enhancement of the Physical Profile of Heat-Moisture Treated Matrices

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Abstract—**Impact of commercial dried sour doughs (SD) addition to blended wheat: millet (WT:MI, 60:40, wt:wt) flour matrices previously submitted to heat moisture treatment (HMT) of MI, has been investigated on the doughmaking and breadmaking performances of diluted systems. Soured HMT dough and bread mixed matrices when compared to unsoured HMT counterparts explicited a variable physico-chemical profile, associated to the type and dosage of SD added. Improving effects of SD addition were particularly evident for SDs mixed with wheat/rye milling products in their commercial preparation, giving total titratable acidity (TTA) values (mL NaOH 0.1N/5 g fresh sample) <2.86 in doughs, and providing breads with TTA levels <3.10. Those SDs provided enhancement of dough machinability, delayed gelatinization temperatures and lower transition enthalpies, bigger developed bread volume, improved textural behaviour and finer and homogeneous crumb grain in started HMT blended matrices.**

Index Terms—**flour, heat moisture treatment, sour dough, breadmaking, physical quality**

I. Introduction

Millets provide a major source of energy, essential micronutrients, phytochemicals, vitamins, phenolic compounds, minerals and nutraceuticals, constituting vital components of food security in developing countries [1]. In developed countries, the growing demand for novel tasty and healthy foods and the increasing number of people suffering from celiac disease and wheat intolerances, has driven a new market, consisting of cereal products made from grains alternative to wheat and rye, in which millets have gained a special position as viable raw materials with revisited value addition.

Millets offer a range of health benefits to the consumer. They contain substantial levels of various phenolic compounds [2], much higher than in wheat, and they exhibit health-promoting properties [3], particularly cholesterol lowering properties, which is better for millet than wheat [4], and decreased glycaemic index in the final bread product [5]. With these attributes millets exhibit a huge potential for food production, and in particular for bread baking [6], [7]. Extensive replacement of wheat flour by millet flours to achieve nutritional and health related benefits, encompasses an impairment of the physico-chemical attributes of resulting breads, since millet flour is gluten-free.

Heat Moisture Treatment (HMT) constitutes a clean label alternative to chemical modification for altering the gelatinization and retrogradation properties of flours [8] and doughs [9], and the aggregation/disaggregation equilibrium of proteins [10], providing enhancement of the viscoelastic character of gluten-free hydrated flours. HMT of flours has successfully been applied to composite oat-wheat [11] flours to improve both volume and textural profile of the resulting breads.

The addition of sour dough (SD) influences all aspects of bread quality and thus meets the consumer demands for a reduced use of additives [12]. Physicochemical changes in the protein network resulting from sourdough fermentation enhance gas retention and allow greater expansion due to softer and more extensible doughs. Increased volume correlates with the increased softness of the crumb, and is associated with a reduced rate of staling when a careful control of acidity is made. The drop in pH during fermentation affects cereal proteases and modulates amylase activity. Proteolysis in sourdoughs is mainly based on the pH-mediated activation of endogenous flour proteases. In addition to the pH-dependent cereal proteases and lactic acid bacteria-liberated proteases, glutathione reductase expressed by heterofermentative lactobacilli contributes to depolymerization of gluten protein. Dried or stabilized sourdoughs produced for acidification provided the conceptual template for the increased use of sourdough products as natural baking improvers [13].

Effects of commercial SD on the breabmaking performance of mixed wheat:millet flour matrices submitted to HMT have not been described so far, despite beneficial effects of either SD or HMT on blended flour matrices are known [8]-[11]. In this research, the impact of different dried commercial SD addition at two levels on the enhancement of the physical profile of blended

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HMT matrices of wheat:millet is investigated, and their effects discussed.

II. Experimental

A. Materials

Commercial flours from refined common wheat *Triticum aestivum* (WT), and commercial millet (MI) were obtained from the Spanish market.

Refined WT (70% extraction rate) of 190 x 10^{-4} J energy of deformation W, 0.55 curve configuration ratio P/L, and 58% water absorption in Brabender Farinograph, was used.

Six different commercial sour doughs (Table 1) were from Böcker (Ernst Böcker GmbH & Co. Minden, Germany) and kindly provided by Tecnufar (Spain).

B. Methods

1) Chemical and nutritional composition of flours

Chemical and nutritional composition of native WT and MI flours were characterized as described by [9]. Proximate composition of macronutrients in g per 100 g flour, m. b.: moisture, 14.3 (WT) and 10.9 (MI); protein (g), 12.1 (WT) and 9.1 (MI); fat (g), 1.34 (WT) and 3.56 (MI); total dietary fibre, 1.9 (WT) and 17.0 (MI); digestible carbohydrates, 70 (WT) and 58 (MI).

2) Heat-moisture treatment (HMT) of flours

HMT conditions (15% moisture content, 1 h and 120 ℃) were applied on millet flour (MI+) as described earlier [9] selected on the basis of previous experiments in which maximization of viscometric profile and minimization of loss of hydration properties of hydrated flour samples were applied as criteria [8].

3) Bread making of untreated and HMT blended flours

Soured doughs and breads were prepared from WT:MI+, (60:40, wt:wt) flours. Blended flours (100 g), sour dough (low -L- and high -H- dosages per sour dough, according to Table 1), water (70%, flour + sour dough weight basis), commercial compressed yeast (2%, flour basis), and salt (2%, flour basis), were respectively mixed up to optimum dough development. Fermented doughs were obtained after bulk fermentation (10 min at 28 ℃), dividing (40 g), rounding, molding, panning and proofing up to maximum volume increment (70 min at 28 ℃), and were baked at 225 ℃ for 10 min to make blended breads. 12 different soured samples (6 sour doughs x 2 dosages) coded A, B, C, D E, F at both L and H doses were obtained. Unsoured control doughs and breads (with no added sour dough) were made for native WT:MI-, and thermally treated WT:MI+ blends.

4) Acidification properties of sour doughs, doughs and breads

The pH values were determined by a pH meter. Total titratable acidity (TTA) of samples was measured on 1 g of sour dough, 5 g of fermented dough and 5 g of fresh bread samples respectively, which were homogenized with 50 ml of distilled water for 3 min in a magnetic stirrer, and expressed as the amount (ml) of 0.1N NaOH to achieve a pH of 8.3.

5) Physical measurements of control and soured HMT matrices

Bread mechanical characteristics of untreated and HMT control and soured doughs were performed by applying a double compression cycle in a TA-XT2 texture analyser (Stable Micro Systems, Surrey, UK) using a 1 cm diameter probe, 75 s waiting period, and 60% compression, as described previously [14] to obtain the texture profile analysis (TPA).

TABLE I. Acidification Properties of Commercial Sour Doughs SD

SD	Ingredients	pH	TTA mL NaOH 0.1N/g	Dosage, % flour Low	Dosage, % flour High
A	Buckwheat and quinoa milling products, starter cultures	3.67^d ±0.01	7.95^c ±0.07	8	10
B	wholemeal rye flour, starter cultures	3.07^a ±0.01	12.20^e ±0.01	3	8
C	wheat milling products, starter cultures	3.23^b ±0.01	9.15^d ±0.07	1	3
D	wheat milling products, wheat malt, starter cultures	3.37^c ±0.01	4.05^a ±0.07	2	5
E	quinoa and rice milling products, starter cultures	4.15^e ±0.01	4.20^b ±0.01	5	10
F	wholemeal rye flour, starter cultures	3.23^b ±0.01	18.55^f ±0.07	2	4

The thermal properties of native and HMT flour blends were determined by using a differential scanning calorimeter (DSC-7, Perkin-Elmer, Norwalk, CT). Dough samples were prepared by mixing flour blends with excess water (1:3). For DSC analysis, 50–70 mg of dough samples were weighed in large volume pre-weighed, sealed stainless-steel pans. An empty pan was used as a reference. Simulation of the temperature profile in the center of the bread crumb during baking was performed in the calorimeter under the scanning conditions previously applied [15]. Thermal transitions of samples for gelatinization were characterised by T_o (onset temperature), T_p (peak temperature), T_c (conclusion temperature), and ΔH (enthalpy of gelatinization). The enthalpy calculations were based on dry-flour weight. The samples were analyzed three times, and the data were calculated with a Pyris software (Perkin-Elmer, Norwarlk, CT).

Bread loaf volume was determined using the rapeseed displacement method as in [16]. Specific loaf volume was calculated dividing the loaf volume by the corresponding loaf weight.

Colour determinations were carried out on bread crumb using a Photoshop system according to the method previously described by [17], and results were expressed in accordance with the Hunter Lab colour space.

Parameters determined were *L* (L = 0 [black] and L = 100 [white]), *a* (-a = greenness and +a = redness), *b* (-b = blueness and +b = yellowness), *ΔE* -total colour difference-, and *WI* -whiteness index- [18]. All measurements were made in triplicate.

Crumb grain characteristics were assessed in bread slices using a digital image analysis system as described by [19]. The crumb grain features evaluated were mean cell area, cells/cm^2, cell/total area ratio, wall/total area ratio and crumb area/total cell ratio. In addition, area distribution and cell number distribution were counted and percentage of cell were calculated according to pre-set cell size ranges: <1mm^2, 1-5mm^2, 5-10mm^2, >10mm^2.

Bread textural characteristics (TPA in a double compression cycle) of fresh breads were recorded in a TA-XT2 texture analyser using a 10 mm diameter probe, a 30 kg load cell, 50% penetration depth and a 30 s gap between compressions on slices of 15 mm width [20]. For textural measurements, three slices of two breads were used for each sample.

Multivariate analysis of variance of data was performed by using Statgraphics V.7.1 program (Bitstream, Cambridge, MN). Multiple range test (Fisher's least significant differences, LSD) for analytical variables was applied to know the difference between each pair of means.

III. Results and Discussion

A. Acidification Power

pH values of sour doughs varied from 3.07 (B) to 4.15 (E), and TTA levels as a measurement of the amount of organic acids during fermentation ranged from 4.05 (D) to 18.55 (F) ml NaOH 0.1 N/g for commercial dried sour doughs (Table I). A final pH range from 3.5 to 4.3, is usually considered as an index of a well-developed sourdough fermentation in wheat-based systems [21]. The pH of the sourdough influences the values of pH of the final dough and bread, depending on the amount of full sour that is used as the inoculum. In our case, values of pH that range from 4.15 to 5.74 are found in the final doughs, that encompassed TTA levels ranging from 1.98 to 3.69 (mL NaOH 0.1N/5g fresh dough).

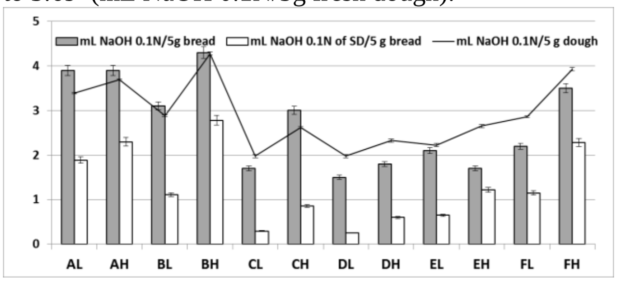

Figure 1. Total titratable acidity of commercial sour doughs (SD A to F), bread doughs, and breads at low (L) and high (H) SD addition.

Acidity values in breads (mL NaOH 0.1N/5g fresh bread) were in general higher in samples soured with H dose of SD (3.10-4.35mL) than in those started with L dose (1.45-3.85mL), in good accordance with the increased contribution of SD acidity to TTA of final breads –from 17 to 52% (L) *vs* 28-65% (H) (Fig. 1). As expected, unsoured samples WT-MI- (CTRL-), and WT-MI+ (CTRL+) exhibited higher pH (5.86, 5.77) and lower TTA (2.00, 1.13mL NaOH/5 g) values in fresh breads than soured samples did.

B. Significance of SD on the Functional Performance of Blended HMT Matrices

Doughs

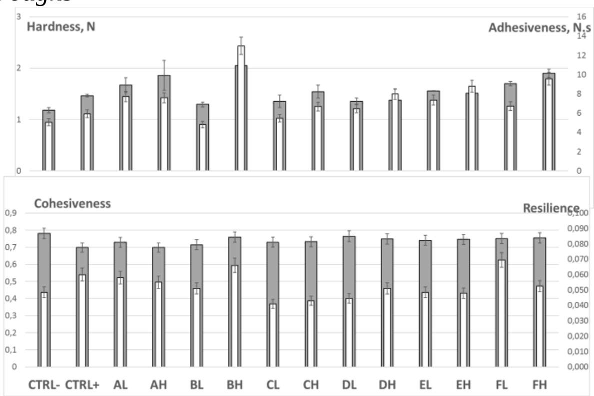

Figure 2. Mechanical and surface-related properties of unsoured and soured bread doughs started with commercial sour doughs (A-F) at low (L) and high (H) dosages. Grey bars (primary axe) refer to hardness and cohesiveness, white bars (secondary axe) refer to adhesiveness and resilience.

SD type and dosages significantly ($p<0.05$) affected mechanical parameters of soured bread doughs (Fig. 2). In general, L dosages of any SD compared to H doses provided softer (1.43N *vs* 1.63N), and less adhesive (6.22 N.s *vs* 8.50 N.s) bread doughs. The type of SD largely influenced dough machinability: harder (A, B, E, F) *vs* softer (C, D) doughs, higher (B, F) *vs* lower (C) adhesive, and higher resilient (C) doughs, in good accordance with TTA values (mL NaOH/5g fermented dough) for soured bread doughs (2.23-4.27 -A, B, E, F- *vs* 1.98-2.62 -C, D-). Interactive effects between SD type and dosage were observed, in such a way that suitable trends for mechanical features including softer, low adhesive and high cohesive and resilient doughs were met by incorporation of SD B at L dose and/or C at both L and H dosages (Fig. 2).

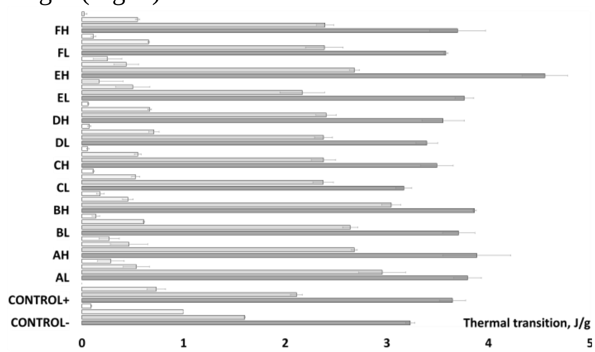

Figure 3. Enthalpies of gelatinization of wheat flour (peak 1: dark grey bar) and millet flour (peak 2: medium grey bar), and enthalpies for dissociation of the amylose-lipid complexes (form IIa: light grey, form IIb: white bars) in blended bread dough systems started with commercial sour doughs (A-F) at low (L) and high (H) addition.

During gelatinization, hydrated mixed flours explicited four endothermal transitions in unsoured and soured matrices with different enthalpies (Fig. 3), associated to gelatinization of wheat and millet flours and to the amylose-lipid complex dissociation. Two thermally distinct forms of amylose–lipid complexes have been identified: an amorphous structure with a random distribution of aggregated helices (termed Form I) with an endothermic transition in the DSC near 100 ℃, and crystalline structures with DSC transitions at about 115 ℃ (Form IIa) and 125 ℃ (Form IIb) [22]. Thermal transitions were ascribed to wheat flour gelatinization (peak 1), millet flour gelatinization (peak 2), amylose-lipid complex dissociation form I (peak 3), and amylose-lipid complex dissociation form II (peak 4). The thermal transitions for peak 1 were more energetic (ΔHg: 3.110-4.712 J/g flour), occurred at lower and closer temperatures (Tp: 64.32-68.83 ℃) and exhibited a broader gelatinization temperature range (R: 12.82-16.67 ℃) than those for peak 2 (ΔHg: 1.60-3.11 J/g flour; Tp: 78.96-82.67 ℃; R: 8.78-16.00 ℃). Thermal transitions for peak 3 and peak 4 were low energetic (ΔH_3<1, ΔH_4<0.4 J/g flour) and took place at higher temperatures (T_{p3}: 96-99 ℃, T_{p4}: 115-126 ℃). In general, the endothermal transitions peak 1 and peak 2 for gelatinization of soured doughs and HMT control WT-MI+ encompassed higher values for both temperatures and enthalpies but narrower temperature range R than did the untreated control WT-MI- doughs. An increase in T_o, T_p, and T_c is a reflection of melting of crystallite which are formed as a result of amylose–amylose interaction and amylose–amylopectin interaction along the chains, as well as chemical bonding/interactions that occur during HMT [23]. This suppresses the swelling of the granule leading to delayed gelatinisation and a high onset, peak and conclusion temperature [24]. Observed increase in both temperature and enthalpies with HMT are in agreement with previous results found earlier for millet [25]. Effects of type and dosage of SD on the parameters of thermal transitions were discreet, and affect mainly enthalpy values of gelatinization. Higher SD dosages H encompassed higher values for gelatinization enthalpies compared to lower dosages L. Values were 3.81 *vs* 3.52 J/g (ΔH_1) and 2.53 *vs* 2.36 J/g (ΔH_2). SD C and E exhibited the lowest 3.166 J/g) and highest (4.550 J/g) values for ΔH_1, respectively.

Breads

Functional performance of unsoured controls and soured HMT breads were characterized at macroscopic and structural levels in terms of specific volume (Fig. 4), colour (Table II), textural (Fig. 5) and crumb grain parameters (Table III, Fig. 6).

Specific volume (mL/g) developed by soured breads ranged from 2.29 to 2.67, values being highly dependent on both the type of SD and the dosage used (Fig. 4). In general, L dosages of SD led to higher bread volume than H dosages (2,43 *vs* 2,32).

This is especially true for sample CL that developed the largest volume (2.67mL/g) within unsoured and soured breads (Fig. 4).

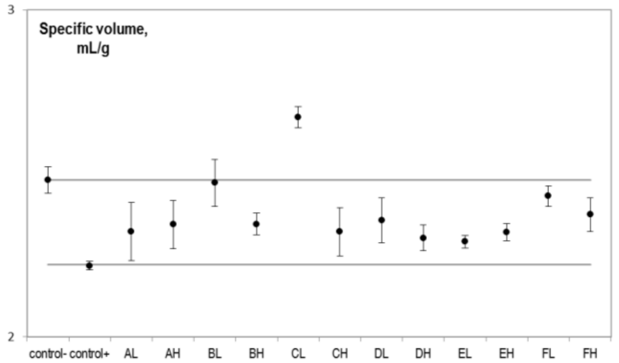

Figure 4. Specific volume of unsoured and soured breads started with commercial sour doughs (A-F) at low (L) and high (H) addition doses. Horizontal lines refer to values of control unsoured samples.

TABLE II. Colour Parameters of Unsoured and Soured Breads Started with Commercial Sour Doughs (A-F) at Low (L) and High (H) Dosages.

Bread Code	*L*	*a*	*b*	*WI*	Δ*E*
control-	80.2^{a}±7.1	-0.95^{b}±0.02	14.44^{a}±0.54	75.5^{k}	6.1
control+	74.4^{a}±8.8	0.77^{k}±0.01	15.09^{ab}±0.57	70.3^{h}	0.0
AL	69.5^{a}±9.0	0.62^{j}±0.01	18.51^{d}±0.91	64.3^{b}	6.0
AH	71.9^{a}±8.0	-0.53^{g}±0.01	18.01^{cd}±0.73	66.6^{d}	4.1
BL	76.0^{a}±8.0	0.52^{i}±0.01	17.36^{cd}±0.79	70.4^{h}	2.8
BH	71.2^{a}±8.1	-1.17^{a}±0.02	17.83^{cd}±0.74	66.1^{c}	4.6
CL	79.6^{a}±7.3	-0.36^{h}±0.01	16.94^{bcd}±0.77	73.5^{j}	5.6
CH	75.1^{a}±9.0	-1.20^{a}±0.02	16.84^{bcd}±0.78	69.9^{h}	2.7
DL	71.4^{a}±7.9	-0.70^{e}±0.01	14.24^{a}±0.54	68.1^{e}	3.4
DH	73.3^{a}±8.2	-0.74^{d}±0.01	14.96^{ab}±0.54	69.4^{f}	1.8
EL	74.8^{a}±8.9	-0.57^{f}±0.01	14.96^{ab}±0.61	70.7^{i}	1.4
EH	73.3^{a}±8.5	0.89^{l}±0.01	15.98^{abc}±0.69	68.9^{f}	1.4
FL	70.0^{a}±9.6	1.68^{m}±0.03	16.17^{abc}±0.63	65.8^{c}	4.7
FH	66.2^{a}±10.1	-0.80^{c}±0.01	16.06^{abc}±0.65	62.5^{a}	8.4

Remaining samples exhibit volumes between those of unsoured untreated WTMI- (2.48mL/g) and HMT WTMI+ (2.22mL/g) counterparts (Fig. 4). Increases in specific volume in bread containing optimal levels of sourdough have been previously reported [21].

In general, soured breads were visibly different from unsoured HMT control breads (ΔE>3) (Table II), and exhibited, with some exception, similar lightness *L* (66.2-79.6 *vs* 74.4), lower *a* (-1.17 to 1.68 *vs* 0.77) and higher *b* (≤18.5 *vs* 15.1) values, resulting in slightly lower WI crumbs (62.5-73.5 *vs* 70.3), particularly for samples started with wholemeal SD at higher dosages like samples A, B and F (Table I). Colour coordinates of blended bread crumbs were dependent on both the type and the dosage of SD. Low dosages of SD C, D, and E, and high doses of SD A, B, C, D, and F led in general to negative *a* values (green), while L dosages of SD A, B, F and H doses of SD C exhibited positive *a* values (red) (Table II).

TABLE III. CRUMB GRAIN PARAMETERS OF UNSOURED AND SOURED BREAD DOUGHS STARTED WITH COMMERCIAL SOUR DOUGHS (A-F) AT LOW (L) AND HIGH (H) DOSAGES.

Crumb grain	Coded breads											
	AL	AH	BL	BH	CL	CH	DL	DH	EL	EH	FL	FH
Cells/cm2	114^{e}	97^{d}	70^{b}	50^{a}	69^{b}	65^{b}	115^{e}	75^{c}	77^{c}	76^{c}	106^{e}	95^{d}
Cell to total area ratio, %	51^{d}	51^{d}	45^{b}	45^{b}	43^{a}	52^{d}	51^{d}	48^{c}	46^{bc}	49^{cd}	44^{b}	50^{d}
Wall to total area ratio, %	49^{a}	49^{a}	55^{b}	55^{b}	57^{b}	48^{a}	49^{a}	52^{ab}	54^{b}	51^{a}	56^{b}	50^{a}
Cell area distribution,%												
$<1mm^2$	14	12	15	12	19	11	11	9	13	9	14	12
$1-5mm^2$	32	19	28	19	42	26	22	17	32	13	22	25
$5-10mm^2$	26	19	25	14	21	15	21	17	16	26	28	24
$>10mm^2$	28	49	32	54	18	48	45	57	39	51	36	39
Cell number distribution, %												
$<1mm^2$	92	93	88	88	86	88	94	92	90	92	94	91
$1-5mm^2$	6	5	8	8	11	9	4	5	8	4	4	6
$5-10mm^2$	2	1	2	2	2	2	1	2	1	2	2	2
$>10mm^2$	1	1	1	2	1	2	1	2	1	2	1	1

Digital image analysis is a useful tool to objectively quantify crumb grain characteristics of different bread types and to track changes in crumb structure. The addition of sourdough to wheat bread has proven to significantly affect both texture and crumb grain characteristics of the baked product [26]. The level of sourdough addition affected the nature and extent of these effects. Crumb grain features of soured HMT breads evidenced a significant dependence ($p<0.05$) firstly on the type of SD and secondly on the dose of addition (Table III). Common structural characteristics included similar cell and wall area ratio at about 50:50, and predominant small alveoli <1 mm^2 (at about 90% in number). L doses provided in breads higher cell density (69-115 cells/cm^2) than H doses (50-97cells/cm^2) attributed to a high area occupied by medium size predominant cells ranging 1-10 mm^2 (43-58% *vs* 33-49%).

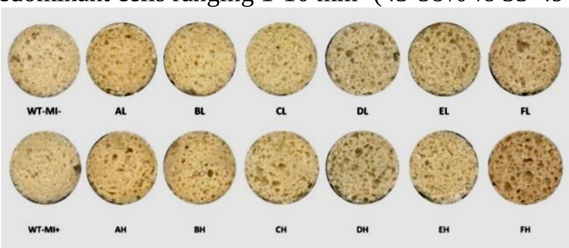

Figure 5. Crumb grain of unsoured and soured breads started with commercial sour doughs (A-F) at low (L) and high (H) addition doses.

Concomitantly, lower area covered by large cells >10 mm^2 and higher surface by small cells <1mm^2 were observed in L dose breads (18-45%, 11-19%) compared to H dose breads (39-57%, 9-12%). As a result, L dose bread crumbs explicited a denser and more packed structure with medium size predominant alveoli with thinner cell walls than H dose bread crumbs did (Fig. 5). Bread crumbs exhibiting finer and more uniformly-sized cell structure with similar cell walls thickness corresponded to soured sample CL and CH, whose crumb grain features are superior compared to unsoured control samples WTMI- and WTMI+, in terms of homogeneity, aeration and fineness (Fig. 5).

An improvement of the internal grain structure with heat treatment was previously found by [27] Gélinas (2001) for substandard flour and by Marston et al (2016) [28] for sorghum breads.

The three dimensional structure of a food is characterised by the organisation of its macroscopic, microscopic and molecular components [29].

The overall texture of the food depends on the three dimensional network formed from its individual omponents. There is evidence from the literature that in baked products the small holes or voids in the crumb, usually referred to as crumb cell structure or crumb grain, contribute to texture, eating quality, mechanical strength and perceived product freshness [30]. Possible relationships between crumb grain and crumb firmness, chewiness and resilience were established [26] in sour dough wheat bread.

The mechanical profile of soured HMT breads evidenced significant differences according to both the type and the dose of SD starting samples (Fig. 6). Suitable textural profile includes lower hardness and higher cohesiveness, springiness and resilience values, while harder, low cohesive with low springiness and resilience crumb breads are unsuitable. When individual mechanical characteristics are considered, softer crumbs were attained by soured breads FL (28.65N) and CL (27.26N), while harder crumbs were those of breads AL (51.08N), CH (50.14N) and EL (54.73N). Concerning cohesiveness, higher values were provided by bread CH (0.503) compared to breads FL (0.330), and AH (0.340) reaching the lower values (Fig. 6). Elasticity of breads in terms of percent and rate of recovery after applying a compression stress pointed out samples CH and FH as those with higher springiness (0.955, 0.853) and resilience (0.202, 0.175), in opposition to samples FL (0.642, 0.107) and AH (0.704, 0.126) exhibiting the lower values for both characteristics, respectively. Overall textural quality at macroscopic level (Fig. 6) is in good accordance with crumb grain features in terms of homogeneity, aeration and fineness (Fig. 5), confirming previous observations [26].

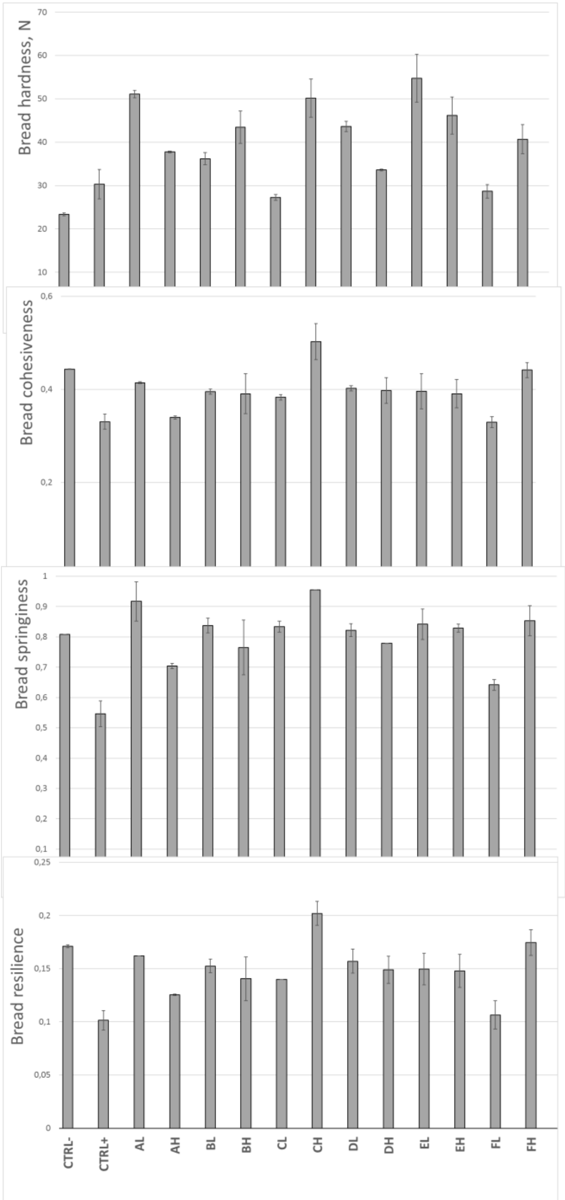

Figure 6. Textural parameters of unsoured and soured breads started with commercial sour doughs (A-F) at low (L) and high (H) addition doses.

IV. Conclusion

In general, soured HMT dough and bread WT:MI mixed matrices when compared to unsoured HMT counterparts explicited a variable physico-chemical profile at macroscopic, microstructural and molecular levels in terms of acidification power, mechanical/ textural behaviour, thermal profile during gelatinization, volume, and crumb grain, associated to the type and dosage of SD added. Improving effects of SD addition were particularly evident for SDs mixed with wheat/rye milling products in their commercial preparation, giving TTA values (mL NaOH 0.1N/5 g fresh sample) <2.86 in doughs, and providing breads with TTA levels <3.10. Those SDs provided enhancement of dough machinability, developed bread volume, textural behaviour and crumb grain in started HMT blended matrices. Gained overall physical quality in soured HMT samples was superior than performance of unsoured either untreated or HMT matrices. Commercial sour doughs under controlled acidity conditions constitute a useful and natural way for improving the breadmaking performance of diluted weakened dough matrices with high replacement of wheat flour by thermally treated millet flour.

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Background: current lines of research

- Cereal Science and Technology: Breadmaking.
- Functional and biochemical assessment of flour-dough-bread along breadmaking: dough rheology, biochemistry of dough fermentation, metabolism of microbial starters.
- Dough functional parameters for predicting the quality and stability of baked products in early stages of processing
- Structural Ingredients in complex dough matrixes: interactions gluten-lipid-starch.
- Bread quality: physico-chemical aspects of bread storage: mechanisms for bread staling.
- Design, development and evaluation of value-added cereal-based products: physico-chemical and nutritional quality and stability of cereal matrices with diluted or lacked biopolymers (gluten and/or starch) for specific groups of population.