EFFECT OF OZONE ON THE RHEOLOGICAL PROPERTIES OF FLOURS AND DOUGH OF FRENCH SOFT WHEAT

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Abstract

Because ozone can promote oxidation and/or degradation of chemical constituents present in the treated material (i.e. proteins, lipids, starch) due to its strong oxidizing properties, we have studied the effect of ozone on the main rheological properties of flour and dough of soft wheat. The results obtained showed that gaseous ozone leads to profound changes in the rheological behaviour of the products generated (i.e. flour-water suspensions, dough after mixing and finished French bread-making products).The results obtained from the BIPEA bread-making tests fully confirm all the conclusions drawn from the various indirect rheological evaluations. Thus, the breads obtained from the baking of ozonated grains are less developed with bread volumes are greatly reduced and a significant drop in their overall bread-making score.

Key-words: Wheat flours and doughs, ozone treatment, rheological properties, bread making quality.

Introduction

Ozone is a powerful oxidizing agent highly reactive which finds increasing applications in many different fields. In 1997, ozone was recognized by U.S. Food and Drug Administration (FDA) as a GRAS (i.e. Generally Recognized as Safe) substance for use as a disinfectant or sanitizer in food industry [1]. However, due to its strong oxidizing properties, ozone is not universally beneficial because, in some cases, O_3 can promote oxidation and/or degradation of chemical constituents present in the treated material (i.e. proteins, lipids, starch) [2-5]. For soft wheat grains, these molecular modifications may cause changes in the rheological properties of the products generated. The objective of this study is to evaluate the main modifications of the rheological properties of flour and dough.

Material and methods

Plant material and experimental design

Two bread wheat cultivars were used in this study (Rubisko and Diamento) differing on their HMW-GS composition (2*/7+8/5+10 and 0/6+8/2+12 respectively). All ozone treatments were conducted with a specific 15 kg semi-batch reactor. A 3-factor 3-level factorial Box-Behnken experimental design was employed [4,5].

Comparison of the different viscosity profiles of flours (Rapid Visco Analyser)

3.50 g ± 0.01 g wheat flour is weighed and 25.00 g ± 0.05 water added to the well. The sample is then placed in the apparatus (RVA, Newport Scientific). The resistance to rotation is measured at 160 rpm during the heating / cooling cycle. The suspension is first heated from 50 to 95 ° C in 3.7 minutes, the temperature is then maintained at 95 ° C for 2.5 minutes and then cooled to 50 ° C in 3.8 minutes. The gel formed is maintained for 2 minutes at 50 ° C., still under constant stirring (160 rpm). The total duration of the analysis is 13 minutes. The device is calibrated using a known reference starch sample.

Study of the behaviour of flours during mixing (Mixograph)

Analyses were carried out using a standardized mixograph (10g version, National Manufacturing, TMCO, Lincoln, NE) in the quality laboratory of the INRA GDEC/UBP station (UMR 1095). Connected to Mixsmart software (version 3.40) for data acquisition and processing, the device used allows the recording of 40 different variables. Only the most relevant ones have been selected for the rheological characterization of flours (MPT, MPV, MPW, MLV, MLW, MTxV, MTxW, MRV, MRW, MTi and WS) [6]. To estimate the maximum water absorption, the standardized method AACC 54-40A has been applied.

Behavior of dough after mixing (Chopin Alveograph)

Alveographic measurements were realized following the NF ISO 5530-4 standard.

Determination of breadmaking quality of flour (BIPEA test)

The evaluation of the breadmaking quality of the flours generated during our studies was carried out using the BIPEA bread-making test, according to the French standard NF V03-716.

Results and discussion

1- Comparison of the different viscosity profiles of wheat flours

The different hydro-thermal profiles of the treated flours were made using a RVA standardized protocol. The objective here is to follow the evolution of the viscosity of a flour-water suspension during its heating and cooling with constant stirring. From Table I, which summarizes all the results obtained, several remarks can be made:

(i) There is not a strictly linear relationship between the measured viscosity and the amount of ozone consumed by the soft wheat grains;
(ii) The different viscosities measured (i.e. maximum viscosity, final viscosity, and retrogradation) do not change in the same way according to the amounts of ozone consumed by the wheat grains.

Table I – Viscosimetric characteristics (RVA) of the various ozonated samples of soft wheat flour.

Sample	Diamento cv.						Rubisko cv.					
	Consumed O_3 ($g.kg^{-1}$ grains)	Viscosity Peak (cP)	Viscosity Min (cP)	Final Viscosity (cP)	Viscosity Decrease (cP)	Retrograd (cP)	Consumed O_3 ($g.kg^{-1}$ grains)	Viscosity Peak (cP)	Viscosity Min (cP)	Final Viscosity (cP)	Viscosity Decrease (cP)	Retrograd (cP)
Control	0.00	2291	1540	2945	751	1405	0.00	2114	1422	2690	692	1268
1	2.16	2132	1495	2816	637	1321	1.91	1967	1386	2582	581	1196
2	4.01	2071	1431	2705	640	1274	3.91	1768	1242	2356	526	1114
3	4.97	2131	1460	2769	671	1309	5.40	1939	1386	2560	553	1174
4	2.57	2325	1577	2990	748	1413	2.86	2086	1440	2705	646	1265
5	2.79	2219	1540	2891	679	1351	3.12	2011	1398	2630	613	1232
6	4.84	2212	1530	2849	682	1319	5.18	1939	1345	2529	594	1184
7	11.12	2361	1482	2765	879	1283	11.50	2207	1435	2651	772	1216
8	6.73	2155	1483	2792	672	1309	6.38	1971	1399	2605	572	1206
9	6.28	2175	1490	2790	685	1300	6.65	2019	1397	2602	622	1205
10	12.38	2379	1503	2788	876	1285	12.47	2279	1491	2720	788	1229
11	14.51	2395	1491	2766	904	1275	13.62	2270	1484	2685	786	1201
12	6.49	2200	1466	2805	734	1339	6.06	2011	1408	2629	603	1221
13	7.87	2256	1507	2784	749	1277	7.84	2019	1385	2594	634	1209
14	7.97	2182	1458	2734	724	1276	7.76	1996	1373	2551	623	1178
15	7.54	2202	1480	2763	722	1283	7.13	2022	1388	2588	634	1200
17	16.11	2595	1505	2737	1090	1232	18.09	2601	1574	2805	1027	1231
18	1.42	2232	1538	2911	694	1373	1.65	2046	1408	2660	638	1252

Thus, the increase in the maximum viscosity seems to occur only after a certain amount of ozone consumed (i.e. beyond 10 g of $O_3.kg^{-1}$ grains) and this, whatever the soft wheat cultivar retained.

The final viscosity is negatively correlated with the ozone consumption for Diamento whereas, on the contrary, this viscosity remains relatively stable or even increases slightly for Rubisko. This criterion is generally used to evaluate the quality of an end product since it reflects the ability of a suspension to form a viscous dough and/or gel after cooking and cooling.

Furthermore, these results show that the ozone treatment seems to limit the tendency of retrogadation of the flour-water suspensions for the Diamento. The phenomenon is much less marked for Rubisko.

2- Study of the behavior of flours during mixing

In order to study the mixing behavior of the different flours treated with ozone we used a mixographic procedure with a standardized protocol. Table II synthesises the values of MPTi and MTxi obtained with during the experimental design chosen.

The parameter MTxi (i.e. area under the curve during the first 8 minutes of mixing), can be likened to the strength of the dough [4]. This important parameter is negatively correlated with the amount of ozone consumed by the grains during their treatment. Although the intensity of this correlation seems to be greater for Diamento samples, the behavior of Rubisko doughs complies perfectly with this general trend.

Table II – Variations of mixograph parameters (MPTi and MTxi) for soft wheat flours as a function of the intensity of the ozone oxidation of the original grains.

Sample	Diamento cv.			Rubisko cv.		
	Consumed O_3 (g.kg^{-1} grains)	MTxi (%)	MPTi (min)	Consumed O_3 (g.kg^{-1} grains)	MTxi (%)	MPTi (min)
Control	0.00	264.91	7.30	0.00	251.98	6.42
1	2.16	227.59	>10.0	1.91	225.85	7.37
2	4.01	227.57	>10.0	3.91	226.69	6.83
3	4.97	218.58	>10.0	5.40	214.38	>10.0
4	2.57	245.80	>10.0	2.86	240.95	7.23
5	2.79	235.87	>10.0	3.12	234.79	>10.0
6	4.84	222.39	>10.0	5.18	257.93	>10.0
7	11.12	190.31	>10.0	11.50	220.48	>10.0
8	6.73	218.59	>10.0	6.38	252.76	>10.0
9	6.28	232.74	>10.0	6.65	226.61	>10.0
10	12.38	193.11	>10.0	12.47	208.83	>10.0
11	14.51	210.04	>10.0	13.62	228.45	>10.0
12	6.49	207.64	>10.0	6.06	223.35	>10.0
13	7.87	202.84	>10.0	7.84	228.62	>10.0
14	7.97	212.89	>10.0	7.76	231.97	>10.0
15	7.54	213.96	>10.0	7.13	222.01	>10.0
17	16.11	182.35	>10.0	18.09	198.58	>10.0
18	1.42	228.37	>10.0	1.65	261.11	>10.0
r		*-0.85**	---		*-0.67**	---

2.1- Study of the consistency of soft wheat doughs

The concept of consistency refers to a set of rheological parameters whose main components are viscoelasticity and extensibility. The consistency of the dough was defined from the heights of the oscillations of the mixograph at different mixing times. Table III summarizes the different consistency values for the different doughs obtained and for the different mixing times (8, 9, and 10 min, respectively) of each treatment.

The results follow the same trend as those obtained for MTxi; these are negatively correlated with the quantities of ozone consumed by the grains during their treatment. The greater the amount of ozone consumed by the wheat grains, the lower the consistency of the dough formed in the mixing conditions fixed by the test. Although this trend can be verified for the two wheat genotypes retained, this one is more marked for the samples of Diamento. Finally, for the same ozonation treatment, there is no difference in consistency observed at the different mixing times studied (i.e. 8, 9 and 10 minutes).

Table III – Variations in the consistency of soft wheat doughs at different mixing times as a function of the intensity of the ozone oxidation of the original grains.

Sample	Diamento cv.						Rubisko cv.					
	Consumed O_3 (g.kg^{-1} grains)	MLV (%)	MPV (%)	MRV (%)	MTxV (%)	MTV (%)	Consumed O_3 (g.kg^{-1} grains)	MLV (%)	MPV (%)	MRV (%)	MTxV (%)	MTV (%)
Control	0.00	27.84	27.92	27.75	27.88	27.69	0.00	26.49	26.60	26.20	26.32	25.76
1	2.16	24.67	25.03	NA	24.31	25.02	1.91	24.11	24.15	22.86	23.63	22.90
2	4.01	24.42	24.83	NA	24.01	24.82	3.91	24.39	24.70	22.07	24.20	
3	4.97	23.08	23.39	NA	22.76	23.38	5.40	23.51	23.98	NA	23.00	23.97
4	2.57	26.44	26.73	NA	26.12	26.73	2.86	25.52	25.45	25.32	25.41	25.27
5	2.79	25.39	25.75	NA	25.02	25.75	3.12	25.29	25.60	NA	24.97	25.59
6	4.84	23.81	24.18	NA	23.43	24.17	5.18	28.21	28.63	NA	27.80	28.62
7	11.12	19.71	19.74	NA	19.67	19.74	11.50	24.75	25.35	NA	24.15	25.33
8	6.73	23.54	23.82	NA	23.26	23.81	6.38	27.50	27.80	NA	27.20	27.79
9	6.28	24.95	25.18	NA	24.72	25.18	6.65	24.96	25.56	NA	24.36	25.54
10	12.38	20.32	20.49	NA	20.15	20.49	12.47	22.64	23.08	NA	22.19	23.07
11	14.51	22.58	22.88	NA	22.29	22.87	13.62	25.07	25.46	NA	24.70	25.45
12	6.49	22.63	22.80	NA	22.46	22.79	6.06	23.97	24.34	NA	23.61	24.33
13	7.87	21.26	21.36	NA	21.16	21.36	7.84	25.64	26.34	NA	24.94	26.33
14	7.97	22.77	23.05	NA	22.48	23.05	7.76	25.69	26.19	NA	25.10	26.18
15	7.54	22.96	23.22	NA	22.71	23.21	7.13	24.41	25.03	NA	23.77	25.02
17	16.11	19.52	19.75	NA	19.28	19.75	18.09	21.77	22.11	NA	21.43	22.10
18	1.42	24.40	24.67	NA	24.13	24.66	1.65	27.40	27.53	27.03	27.22	26.62
r		*-0.85**	*-0.85**		*-0.85**	*-0.85**		*-0.55**	*-0.49**		*-0.57**	*-0.38**

2.2- Study of the mixing tolerance of soft wheat doughs

Conventionally the tolerance to mixing is evaluated according to the thickness of the curve obtained with the mixograph. As with the dough consistency evaluation, the values were recorded at different mixing times (8, 9 and 10 min). All these results are summarized in Table IV. As the results show, the ozonation of wheat grains does not seem to significantly affect the dough mixing tolerance, regardless of the mixing time used in the test.

Table IV – Variations in the mixing tolerance of soft wheat doughs as a function of the intensity of the ozone oxidation of the original grains.

Sample	Diamento cv.						Rubisko cv.					
	Consumed O_3 (g.kg^{-1} grains)	MLW (%)	MPW (%)	MRW (%)	MTxW (%)	MTW (%)	Consumed O_3 (g.kg^{-1} grains)	MLW (%)	MPW (%)	MRW (%)	MTxW (%)	MTW (%)
Control	0.00	10.17	10.01	9.78	9.97	9.73	0.00	7.82	7.49	6.51	6.77	5.41
1	2.16	9.38	8.88	NA	9.26	8.88	1.91	9.19	7.37	11.61	6.90	11.20
2	4.01	12.98	10.37	NA	13.44	10.37	3.91	8.04	7.15	8.70	6.32	11.87
3	4.97	10.42	9.72	NA	10.47	9.72	5.40	8.88		NA	9.07	
4	2.57	8.69	8.40	NA	9.01	8.40	2.86	8.06	7.42	6.07	6.93	5.51
5	2.79	10.13	8.57	NA	10.32	8.57	3.12	7.58	7.20	NA	7.78	7.20
6	4.84	9.30	9.40	NA	9.08	9.40	5.18	9.47	9.07	NA	9.82	9.07
7	11.12	13.06	14.34	NA	12.16	14.34	11.50	9.20	9.08	NA	9.61	9.08
8	6.73	11.43	10.74	NA	11.21	10.74	6.38	7.19	6.80	NA	7.89	6.80
9	6.28	10.51	10.42	NA	10.39	10.42	6.65	8.87	8.18	NA	10.78	8.18
10	12.38	11.79	11.53	NA	11.76	11.53	12.47	10.63	9.86	NA	10.56	9.86
11	14.51	10.41	10.41	NA	10.63	10.41	13.62	9.54		NA	9.87	
12	6.49	11.06	11.51	NA	10.62	11.51	6.06	10.51	9.81	NA	10.75	9.81
13	7.87	12.73	12.32	NA	11.67	12.32	7.84	7.74	6.70	NA	8.84	6.70
14	7.97	10.80	11.28	NA	11.03	11.28	7.76	7.75	7.57	NA	8.20	7.57
15	7.54	9.95	10.25	NA	9.96	10.25	7.13	9.98		NA	10.99	
17	16.11	11.39	12.97	NA	8.46	12.97	18.09	8.14	8.63	NA	8.02	8.63
18	1.42			NA		13.87	1.65	8.76	7.66	6.51	6.86	5.91
r		*0.43*	*0.70**		*0.09*	*0.48**		*0.26*	*-0.49**		*0.48**	*0.26*

3- Study of the behavior of soft wheat doughs after mixing

Table V shows, for the two soft wheat cultivar selected (i.e. Diamento and Rubisko), the variations in the alveographic parameters of the dough in relation with the intensity of the ozonation treatment (i.e. quantity of ozone consumed by the grains).

Table V – Variations in alveographic parameters (W, P and L) of soft wheat doughs as a function of the intensity of the ozone oxidation of the original grains.

Sample	Diamento cv.					Rubisko cv.				
	Consumed O_3 ($g.kg^{-1}$ grains)	W (10^{-4}J)	P (mm)	L (mm)	P/L	Consumed O_3 ($g.kg^{-1}$ grains)	W (10^{-4}J)	P (mm)	L (mm)	P/L
Control	0.00	169	89	47	1.89	0.00	114	55	66	0.83
1	2.16	135	97	31	3.13	1.91	109	59	52	1.13
2	4.01	135	99	31	3.19	3.91	103	52	55	0.95
3	4.97	104	96	24	4.00	5.40	106	61	45	1.36
4	2.57	158	104	34	3.06	2.86	100	58	49	1.18
5	2.79	134	123	24	5.12	3.12	120	73	45	1.62
6	4.84	105	105	23	4.57	5.18	108	61	45	1.36
7	11.12	92	92	24	3.83	11.50	88	76	26	2.92
8	6.73	126	124	24	5.17	6.38	107	73	38	1.92
9	6.28	95	104	21	4.95	6.65	104	83	29	2.86
10	12.38	76	90	20	4.50	12.47	76	80	23	3.48
11	14.51	92	99	23	4.30	13.62	99	97	23	4.22
12	6.49	109	119	21	5.67	6.06	91	77	28	2.75
13	7.87	109	105	27	3.89	7.84	126	74	44	1.68
14	7.97	108	107	24	4.46	7.76	120	87	33	2.64
15	7.54	80	74	25	2.96	7.13	108	77	33	2.33
17	16.11	63	80	19	4.21	18.09	58	69	21	3.29
18	1.42	153	104	33	3.15	1.65	115	67	49	1.37
r		*-0.86**			*0.38*		*0.26*	*-0.71**		*0.85**

The ozonation of the grains causes a significant decrease in the value of W of the corresponding dough. In extreme conditions (i.e. Control *vs.* Treatment 17) this decrease can represent up to - 62% of the initial value (decrease from 169 to 63 × 10^{-4} J) for Diamento samples and - 49% of the value initial (decrease from 114 to 58 × 10^{-4} J) for Rubisko samples. This drop in W (i.e. baking strength) is perfectly consistent with the observed behaviour of the strength of the dough during mixing (MTxi).

At the same time, the ozonation of the grains causes a very significant modification of the P/L ratio; report that reflects the viscoelastic balance of the dough. Under extreme conditions (i.e. Control *vs.* Treatment 17), the ratio P/L will be multiplied by 2.23 (increase from 1.89 to 4.21) and by 3.96 (increase from 0.83 to 3.29) for Diamento and Rubisko samples respectively. This modification of the P/L ratio subsequent to the ozonation of the grains thus results in (i) a very important increase in the tenacity of the manufactured doughs and (ii) a drastic decrease in their elasticity.

This phenomenon is much more marked for Rubisko (a variety known for its more limited bread making qualities) compared to Diamento. A balance between the parameter W and the P/L ratio is reached around an ozone consumption of about 5g $O_3.kg^{-1}$ grains for Diamento whereas it is reached around 10g of O_3 $.kg^{-1}$ grains for Rubisko. These significant differences must be explained by differences in the initial composition of protein structures (i.e. nature and relative abundance of different glutenin subunits in particular) which are largely responsible for intermolecular protein-protein interactions [5].

In their patent, Yvin et al. [7] also reported an increase in the strength of ozonated grain flour-based dough and a decrease in extensibility, also measured by Chopin's alveograph. On the contrary, during their work, Violleau et al. [8], have observed a stagnation or a slight increase in the W parameter that they associate with polymerization/depolymerization phenomena within the prolamins present in the flours studied.

4- *Study of the bread making quality of wheat flours*

As part of our study, the standardized BIPEA bread making test was set up to confirm the rheological changes observed in previous tests on flours and/or doughs. Indeed, even if this evaluation test is heavy and difficult to implement, it is nonetheless the only direct test to really assess the French bread making quality of wheat flours.

To do this, two parameters were evaluated during this standardized test: (i) the bread volume and (ii) the bread making score itself based on the evaluation of three sub-criteria: (a) the dough score, (b) the bread score and, (c) the crumb score. For each cultivar, hydration was set by the expert baker from a sample of control flour. Thus, this value was maintained at 60.9% (w/w) for Diamento and 60.4% (w/w) for Rubisko. In all the samples the hydration values were kept constant to allow a comparison of the samples between them.

Only four flours for each wheat cultivar were subjected to this BIPEA bread making test: control flours (flours derived from non-ozonated grains), flours corresponding to treatment 18 (i.e. flours derived from slightly ozonated grains), flours corresponding to treatment 14 (i.e. flours from medium ozonized grains) and finally, the flours corresponding to treatment 17 (i.e. flours from highly ozonated grains).

Figure 1 - Photographs of the various bread samples obtained at the end of the bread making test from Diamento (A, B, C and D) and Rubisko (E, F, G and H) flours. Control Flours (A and E), Treatment 18 flours (B and F), Treatment 14 flours (C and G) and Treatment 17 flours (D and H).

For the two soft wheat cultivar studied, the differences are clearly visible in the photographs presented in Figure 1. Thus, the bread from highly ozonated grains (i.e. treatment 17) is less developed, the crumb is tight and a lack of relaxation of the dough is visible by the presence of many bubbles.

The color of the crumb is also very characteristic of the treatment applied. Thus, a cream-hazel then brown coloration is observed for the average treatments (treatment 14) and strong (treatment 17). The Maillard reaction could be one of the hypotheses that can explain this change of color. Finally, the grigne is also modified, we cannot characterize it for the samples C and D. For these two samples, we speak rather of crackling of the crust rather than lack of development of the grigne.

All of these visual defects are confirmed by the overall test scores presented in Table VI.

Tableau VI – Results of the BIPEA bread making test for the different soft wheat flours used. Control flours (flours derived from non-ozonated grains), Treatment 18 (flours derived from slightly ozonated grains), Treatment 14 (flours from medium ozonized grains) and, Treatment 17 (flours from highly ozonated grains).

Sample	Diamento cv.						Rubisko cv.					
	Consumed O_3 (g.kg^{-1} grains)	Dough score (/100)	Bread score (/100)	Crumb score (/100)	Baking score (/300)	Mean bread volume (cm^3)	Consumed O_3 (g.kg^{-1} grains)	Dough score (/100)	Bread score (/100)	Crumb score (/100)	Baking score (/300)	Mean bread volume (cm^3)
Control	0.00	64.38	50.25	100.00	214.63	355 ± 21.30	0.00	98.50	77.80	100.00	276.30	510 ± 12.30
18	1.42	51.63	50.25	100.00	201.88	309 ± 11.10	1.65	98.50	74.80	100.00	273.30	513 ± 11.90
14	7.97	18.63	29.75	91.00	139.38	254 ± 22.90	7.76	50.50	29.00	91.00	170.50	321 ± 22.90
17	16.11	12.88	12.25	82.00	107.13	244 ± 8.80	18.09	15.63	12.63	82.00	110.25	275 ± 8.90

In addition, the results of this test show that the treatment of grains with ozone (i.e. Control flours *vs.* Treatment 17) causes a significant change in the volume of the breads (-111 cm^3 for Diamento and -253 cm^3 for Rubisko); this decrease in volume being strongly correlated with the alveographic parameter "G" (i.e. swelling of the dough) (Figure 2).

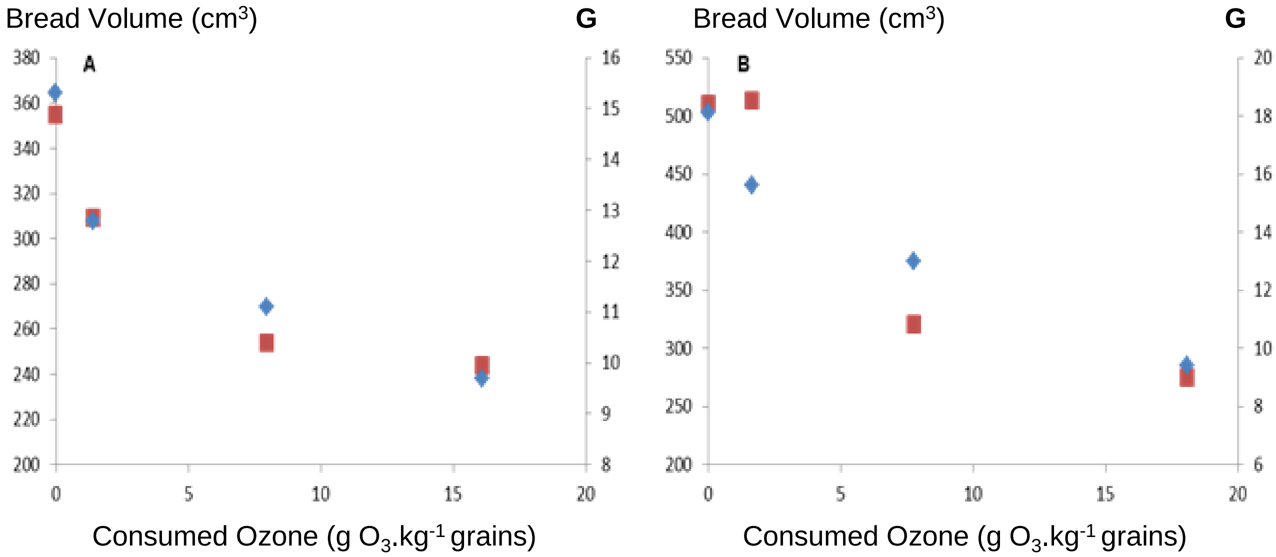

Figure 2 – Variation of the bread volume (■) and the swelling « G » of doughs (◆) as a function of the intensity of the ozone oxidation of the original grains (i.e. consumed ozone). (A) Diamento, (B) Rubisko.

Conclusions

According to these different direct and/or indirect rheological approaches, it is clear that the treatment of soft wheat grains with gaseous ozone leads to profound changes in the rheological behaviour of the products generated (i.e. flour-water suspensions, doughs after mixing and finished products of French bread making).

The viscosimetric characteristics of the different flour-water suspensions obtained after the ozonation treatment of soft wheat grains are deeply affected. Thus, whether it is the maximum viscosity or the tendency to retrogradation, these different variables are greatly limited by the ozonation treatment of the grains from which the suspensions were evaluated.

In the same time, the ozonation of the wheat grains causes a significant change in the behaviour of the different flours obtained during their mixing. Thus, the strength of dough obtained (i.e. MTxi) and their consistency are negatively correlated with the amounts of ozone consumed by the grains during their treatment. On the other hand, the ozonation of the grains does not seem to significantly affect the dough mixing tolerance, whatever the mixing time chosen during the test.

At the end of their mixing, dough done from ozonated grains is characterized by a very significant increase in the P/L ratio (i.e. + 200% to + 400%). These modifications reflect significant increases in tenacity and significant decreases in extensibility within the protein networks formed at the end of mixing. Consequently, these changes in viscoelastic profiles substantially degrade the bread-making character of these doughs.

The results obtained from the BIPEA bread making tests fully confirm all the conclusions drawn from the various indirect rheological evaluations. Thus, the breads obtained from the baking of ozonated grains are less developed with greatly reduced bread volumes and a significant drop in their overall bread-making score.

Ozone can leads to profound changes in the rheological properties of the flours and/or doughs by significantly affecting the molecular properties of wheat grain prolamins [i.e. formation of intermolecular S-S bonds, formation of other types of intermolecular covalent cross-links (dityrosine cross-links) and finally, changes in secondary structure] [5] and/or starch [4]. Therefore, any directed control or modification of the rheological properties of flours and / or soft wheat pastes requires a precise knowledge of the molecular effects of this oxidant on the aggregative properties of the native polymers present.

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