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## Effect of long-term storage conditions on wheat flour and bread baking properties

Eloïse Lancelot, Joran Fontaine, Joëlle Grua-Priol, Alain Le-Bail

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23 • Storage in a sealed container at -20°C enabled the flour quality to be preserved

24 • The loss of quality was mainly due to lipid oxidation

25 • The Hagberg falling number was increasing for flours stored at 20°C

26

## 27 **Keywords**

28 • Wheat flour storage

29 • Wheat flour properties

30 • Bread quality

31 • NIR spectroscopy

32

## 33 **1. Introduction**

34 Storing wheat grains for several months is common practice, whereas flour milling is done  
35 progressively between two harvests. Conversely, flours are usually stored for shorter  
36 durations. Indeed, milling destroys the cell walls so that the different constituents of the flour  
37 are in direct contact with the air and microorganisms, resulting in modifications of flour  
38 parameters. It has often been reported that the quality of flour is improved after several weeks  
39 of storage under good conditions (Baik & Donelson, 2018; Hrušková & Machová, 2002;  
40 Wang & Flores, 1999). Nevertheless, these benefits are short-term, and the prolonged storage  
41 of flours eventually done in unsatisfactory storage conditions, can eventually cause spoilage  
42 (Pylar & Gorton, 1973; Wang & Flores, 1999). Flour spoilage can have several origins: i)  
43 alteration of chemical origin, like protein denaturation, starch degradation, non-enzymatic  
44 oxidations; ii) alteration of enzymatic origin; iii) alteration of mechanical or physical origin,  
45 mainly due to shock, leading to cracks or breakage which favour other causes of alteration  
46 like iv) the invasion of microorganisms (Hackenberg et al., 2017). Factors influencing the

47 evolution of flour include moisture, temperature, the presence of oxygen and/or carbon  
48 dioxide and storage time (Wang & Flores, 1999; Warwick et al., 1979). The relative humidity  
49 of the ambient air can, under certain conditions, increase the water activity, resulting in the  
50 deterioration of organoleptic qualities, and even in mycotoxin production. Moisture can also  
51 contribute to the oxidative deterioration of lipids, resulting in a typical rancid odour and an  
52 increase in the content of free fatty acids. The variation of moisture can be caused by: i) poor  
53 storage conditions, with high air humidity; ii) considerable variations in temperature; iii)  
54 proximity with products that may give off moisture; and iv) pre-harvest weather conditions,  
55 which may increase the moisture content of the product. Air temperature and air humidity  
56 during flour storage are therefore important parameters. Higher air temperature may yield  
57 higher specific humidity (kg Water / kg dry air) and thus more available water, whereas at low  
58 temperature, the contrary is observed. In addition, an increase in temperature accelerates the  
59 rate of deterioration reactions (chemical, biological and microbiological) (Vanhanen &  
60 Savage, 2006). Oxygen and / or CO<sub>2</sub> may also affect the nature of the aerobic and anaerobic  
61 metabolism of microorganisms (Navarro, 2012), and the level of non-enzymatic oxidation and  
62 certain enzymatic reactions (Zia-Ur-Rehman, 2006). Finally, storage time is a factor that  
63 amplifies the alteration phenomenon (Wang & Flores, 1999). Several researchers have  
64 examined the effects of ageing on different flours (Bell et al., 1979; Brandolini et al., 2010;  
65 Hrušková & Machová, 2002; Mis, 2003; Sopiwnyk et al., 2020; Vanhanen & Savage, 2006;  
66 Warwick et al., 1979; Zarzycki & Sobota, 2015). In these studies, the packaging, storage  
67 conditions, duration and the flour parameters analysed were different each time. Most of them  
68 were limited to one year of storage or less. Hrušková and Machová (2002) analysed the  
69 moisture, wet gluten, acidity, falling number and alveograph results of two commercial wheat  
70 flours stored in jute bags for three months. They showed that the chemical characteristics and  
71 viscoelastic properties changed very rapidly during this short storage period. Mis (2003)

72 studied the physical properties of gluten for 32 weeks and observed a gradual diminution of  
73 the quantity of washed out gluten as well as an increase in the Gluten Index value. Zarzycki  
74 and Sobota (2015) considered a storage period of 6 weeks. They focused on the falling  
75 number and apparent viscosity of wheat flour gruels stored in tightly closed containers at  
76 temperatures of 20 °C, 4 °C and -20 °C. They found that the falling number values increased  
77 for flours stored at 20°C and decreased for flours stored at -20°C, and that the viscosity of  
78 wheat flour increased over the 6-week storage period. Brandolini et al. (2010) studied alpha-  
79 amylase activity, falling number, pasting properties and SDS sedimentation volume in whole  
80 meal and white flours of einkorn and soft wheat over a period of 374 days, considering  
81 storage at temperatures ranging between 30°C and -20°C. They showed that alpha-amylase  
82 activity decreased, while falling number, viscosity and SDS sedimentation increased with  
83 ageing. The changes were drastic at high temperatures (38 and 30 °C), but were reduced or  
84 negligible at medium and low temperatures (20, 5 and -20 °C). An effect of the storage  
85 temperature of wheat flours on the falling number and viscosity was also shown. However, in  
86 the case of a PhD project, ideally, flour should be kept for at least three years in order to  
87 ensure good repeatability of the results and to prevent them from being influenced by a  
88 change of batch. In this particular case, maintaining flour quality during storage is very  
89 crucial. Only a few studies have been performed for durations longer than three years.  
90 Warwick et al. (1979) focused on changes in the lipid fraction of flour during 5 years of  
91 storage. The most comprehensive study was carried out by Bell et al (1979). They focused on  
92 the lipolysis rate of flours milled from weak, medium, and strong wheats at three temperatures  
93 (12, 25, and -20 °C in an inert atmosphere) for up to 66 months. They confirmed that  
94 conclusions regarding the baking quality of stored flours must be made with caution, since the  
95 results obtained are highly dependent on the nature of the baking test used. As chemical  
96 analyses were not carried out systematically at regular intervals, some information was

97 missing. This review of past publications shows that none of these studies took into account  
98 the effect of prolonged storage on all the parameters of wheat flour by associating different  
99 storage temperatures and packaging conditions.

100 This study aims at filling this gap by carrying out a more complete investigation on the effect  
101 of storage time and packaging conditions on soft wheat flour over a period of 30 months for  
102 the purpose of determining whether one storage method is more appropriate than another.  
103 Data on chemical composition (water, protein, ash, damaged starch, oleic acidity, Hagberg  
104 falling number and TOTOX), analytical profiles (farinograph, alveograph and Solvent  
105 Retention Capacity) and Near-infrared spectra were collected after 3 months, 6 months, 12  
106 months, 21 months and 30 months of storage for flours stored in two different types of  
107 packaging and two different conditions (paper bag or watertight container at 20 and -20 °C). It  
108 is well-known that Near-Infrared Spectroscopy (NIRS) can predict wheat composition  
109 parameters such as moisture, protein, ash and wet gluten contents with a high degree of  
110 accuracy and it appeared that this technique could also model certain rheological parameters  
111 (farinograph, extensograph, alveograph) (Jirsa et al., 2007). The results presented in this study  
112 also confirmed the interest of Near-Infrared spectroscopy for quantifying most flour  
113 parameters in a rapid and non-destructive way.

114

## 115 **2. Materials and methods**

### 116 **2.1. Materials**

117

118 Commercial type 55 wheat flour was supplied by Moulins Soufflet SA (France). The flour  
119 came from wheat harvested in the 2015/2016 season and contained no additives. A sandwich  
120 bread dough recipe was used for bread-making trials at the beginning of the experiment and  
121 after 30 months. The ingredients used in the recipe were: 100 g wheat flour, 53.5 g tap water,

122 4.5 g vegetable oil, 4.5 g sugar, 1.8 g salt and 0.31 g improver. The temperature of the dough  
123 at the end of mixing was controlled to be around 27°C by adjusting the sum of the room, flour  
124 and water temperatures which was equal to 55°C.

125

## 126 **2.2. Storage conditions of wheat flour**

127

128 The flour was conserved using two different types of packaging: either in 25 kg paper bags  
129 (permeable to oxygen and humidity) or in 26 L HDPE watertight containers (non-permeable  
130 to oxygen and humidity). As shown in Figure 1, sealed flour bags and containers were stored  
131 at controlled temperature (at either 20 °C or cold storage room at -20 °C). The chemical  
132 composition and analytical profiles of the flours (packed in two different types of packaging,  
133 and stored in two different conditions) were determined after 3 months, 6 months, 12 months,  
134 21 months and 30 months of storage,

135

## 136 **2.1. Flour analyses**

137

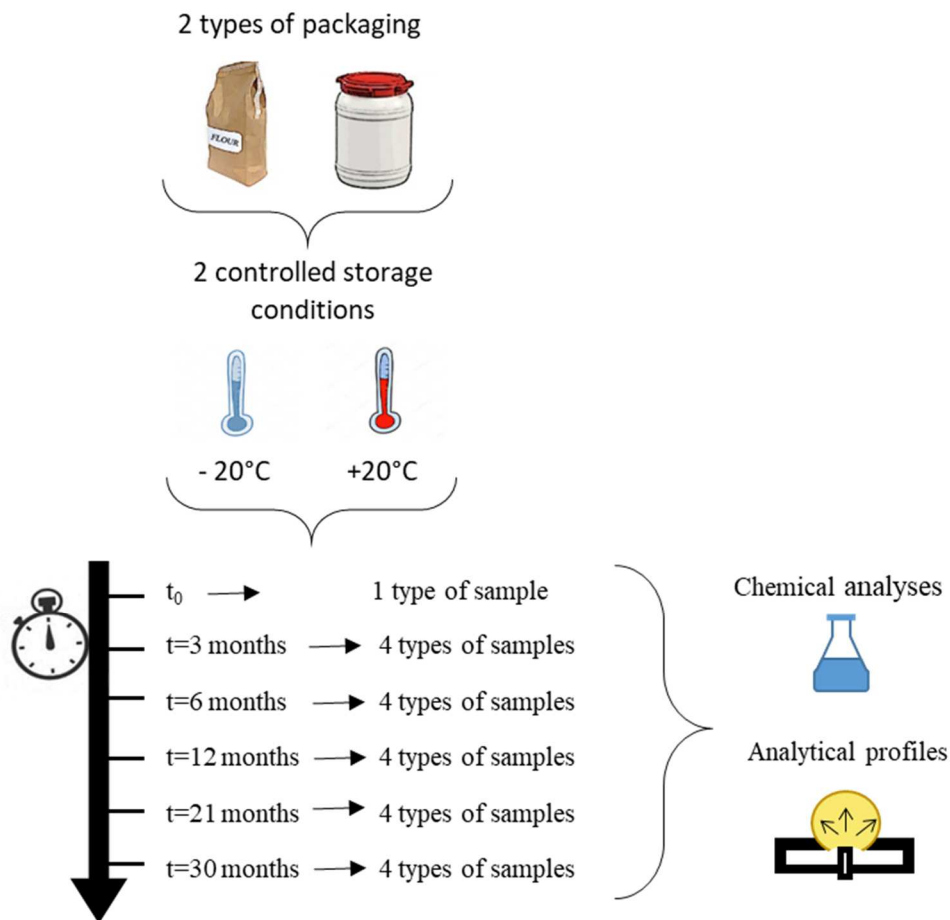
138 Chemical analyses were performed and analytical profiles (alveograph, farinograph and  
139 Solvent Retention Capacity) obtained by Upscience Labs Solution (St-Nolff, France) at t=0,  
140 t=3 months, t=6 months, t=12 months, t=20 months and t=30 months. The principles and  
141 standards of the various analyses performed are summarized in the Supplementary data (Table  
142 1).

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148

*Figure 1: Experimental design: Wheat Flours were packaged and stored under different conditions for up to 30 months*

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150

## 2.2. Bread baking procedure

151

152 The ingredients were mixed using a spiral mixer (SPI 11 – VMI, Montaigu, France). First, a  
 153 pre-mixing step was performed at 100 rpm for 330 s to uniformly disperse the raw materials.

154 Then, kneading was performed at 200 rpm until the optimum mixing time, the so-called “time  
 155 to peak” or “t<sub>PEAK</sub>”, which is set to the time needed to reach the maximum power

156 consumption of the mixer. After a rest period of 3 minutes, dough pieces of 280 ± 5 g were  
 157 cut from the dough mass. Each dough piece was rolled out by hand and left to rest for a

158 further 10 minutes. They were then shaped by hand and placed in moulds. The moulds were  
 159 placed in a Bi-Tronic Control fermentation chamber (Hengel, France) at a relative humidity of



160 80% and a temperature of 40 °C, until they reached a growth corresponding to 200 % of the  
161 initial volume. The time needed to reach this volume was about 50 minutes.

162 Baking was carried out in an MIWE deck oven (Arnstein, Germany). After loading, 300 mL  
163 of water was sprayed onto the loaves. Baking time was programmed for 20 minutes at a  
164 temperature of 220 °C. At the end of baking, the loaves were removed from the moulds and  
165 left to sweat for at least 2 hours at room temperature.

166

### 167 **2.3. Evaluation of bread quality**

168

169 Six breads were analysed using the following method for each storage condition. The breads  
170 were cut into 15 mm thick slices along their entire length using a professional multifunction  
171 slicer (Sofraca, France). Approximately seven slices were obtained for each bread. Then, the  
172 bread slices were scanned one by one against a black background in an Epson scanner (Epson  
173 Perfection V37, Japan). The scan window was set to 120 x 120 mm corresponding to a size of  
174 1889 x 1889 pixels. Each image was processed using Fiji (ImageJ). First, they were converted  
175 into 8-bits and thresholded, then the area and the diameter of each crumb cell were calculated.  
176 The height of the bread slices was estimated by measuring the length of a vertical line drawn  
177 in the middle of the slices.

178

### 179 **2.4. Near-infrared Spectroscopy**

180

181 Near-Infrared (NIR) spectra of flour at t=3 months, t=6 months, t=12 months, t=20 months  
182 and t=30 months were recorded using an ANTARIS MII FT-NIR Analyzer (Thermo  
183 Scientific, France). About 10g of flour was placed in a quartz sample cup spinner and  
184 measured using the integrating sphere module for diffuse reflectance sampling. Triplicates

185 were acquired over the 4000-10 000  $\text{cm}^{-1}$  spectral range with a spectral resolution of 8  $\text{cm}^{-1}$ .  
186 Each spectrum was the average of 16 scans and represented as  $\log(1/R)$  values as a function  
187 of wavelength (nm). A Standard Normal Variate (SNV) transformation was applied to the  
188 data set to remove the particle size effect and scattering offset. Principal Component Analysis  
189 (PCA) of the NIR data was performed using MATLAB R2019b software (The MathWorks,  
190 Inc). This technique extracts the main sources of variability of a set of spectra with no prior  
191 knowledge of the chemical composition of the samples. PCA reduces the dimensionality of  
192 the data while retaining most of the variance in the data set (Dale et al., 2012), by identifying  
193 directions, called principal components, along which the variance of the data is maximal.  
194 Thus, each sample can be represented by a few numbers instead of thousands of variables.  
195 The observation of the distribution of the samples in the PC subspace allows analysing their  
196 common features and/or their grouping.  
197 TQ Analyst 9.5 Software (Thermo Scientific, France) was used to develop prediction models.  
198 The samples were divided into a calibration set of 42 samples, and a validation set of 20  
199 samples. Calibration was carried out by Partial Least Square (PLS) regression. PLS calculates  
200 new variables by selecting the dimensions that explain the maximum variance in both the  
201 spectral range and the dataset. It therefore ensures that the factors derived are correlated to the  
202 reference data (Dale et al., 2012).

203

### 204 **3. Results and discussion**

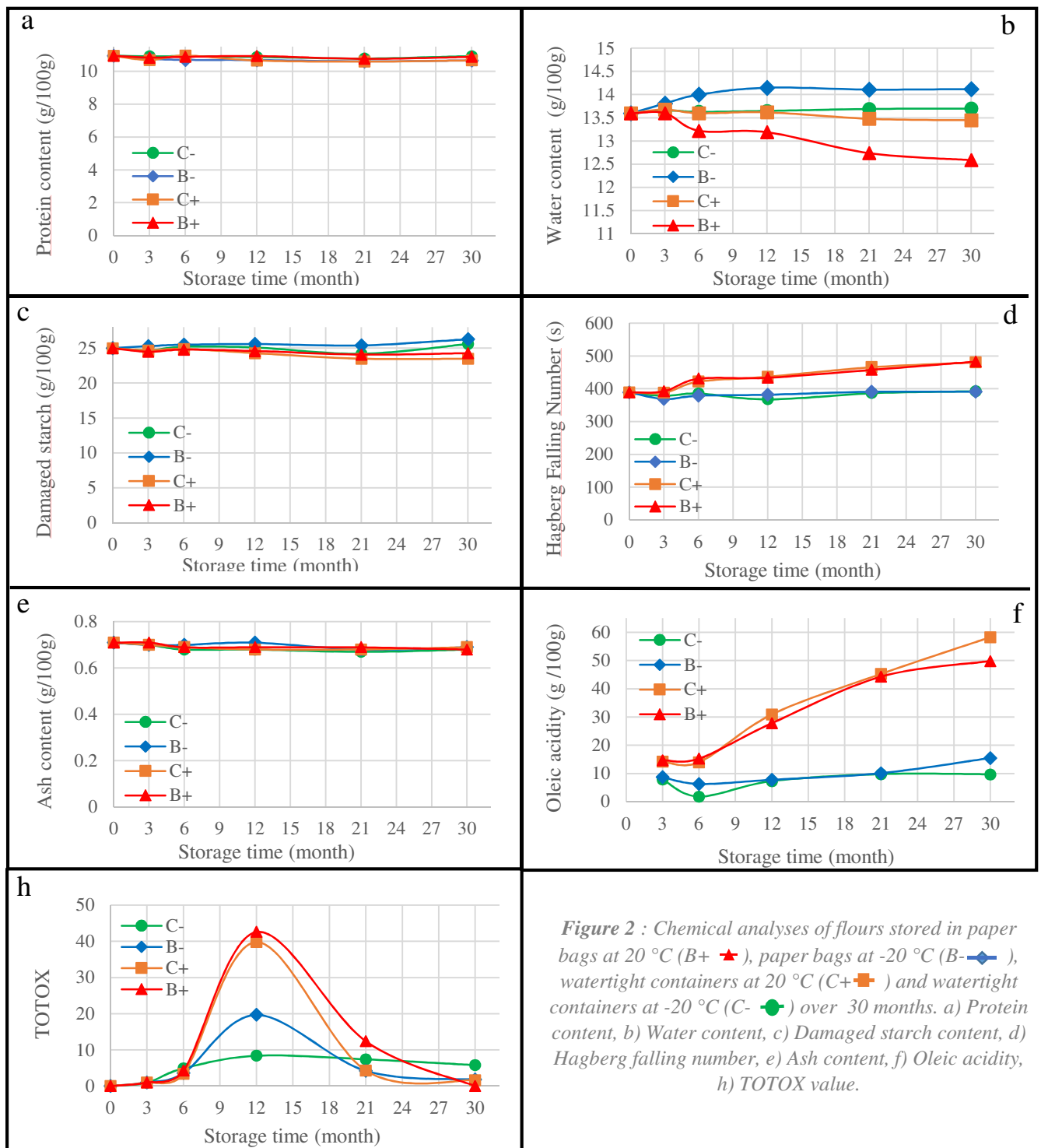
#### 205 **3.1. Flour properties**

##### 206 **3.1.1. Chemical analyses**

207

208 Protein, damaged starch and ash contents remained quite stable during the entire storage  
209 period for all types of packaging (Figure 2 a, c and d). The water content was subject to more

210 drastic variation in the case of packaging in paper bags. An increase of about 1.5 % in water  
 211 content was observed from the first three months of the storage of bagged flours at -20 °C.  
 212 The increase continued during the first year up to about 4% and then stabilized.



*Figure 2 : Chemical analyses of flours stored in paper bags at 20 °C (B+ ▲), paper bags at -20 °C (B- ◆), watertight containers at 20 °C (C+ ■) and watertight containers at -20 °C (C- ●) over 30 months. a) Protein content, b) Water content, c) Damaged starch content, d) Hagberg falling number, e) Ash content, f) Oleic acidity, h) TOTOX value.*

234 Conversely, after three months of storage in a paper bag at room temperature, the water  
235 content gradually decreased to more than 7% after thirty months of storage. Less than 1%  
236 variation was observed for the flours stored in watertight containers (Figure 2 b).

237 The Hagberg falling number tended to increase for flours stored at room temperature while it  
238 remained constant at -20 °C (Figure 2 d). This trend had already been observed in the study of  
239 Brandolini et al. (2010). This means that amylolytic activity decreases during the extended  
240 storage of flours at room temperature.

241 Oleic acidity increased drastically for flour stored at ambient temperature (Figure 2 f),  
242 meaning that the resulting dough would be weaker with reduced strength and increased  
243 plasticity. The hydrolysis of glycerides by wheat and microbial lipases could increase the  
244 amounts of free fatty acids in the flours stored at 20 °C.

245 TOTOX is the total oxidation measurement, taking into account the contribution of the  
246 peroxide value, an expression of primary oxidation, and the anisidine value, an expression of  
247 secondary oxidation. The TOTOX value was used here to obtain overall information on  
248 oxidative degradation during flour storage. The oxidation peak occurred at about one year of  
249 storage before a decrease that could have been due to the better resistance of saturated fats  
250 toward oxidation. This oxidation peak was more pronounced for flours stored at room  
251 temperature (Figure 2 h). Samples stored at -20 °C appeared to have better oxidation stability,  
252 and less tendency to develop rancidity.

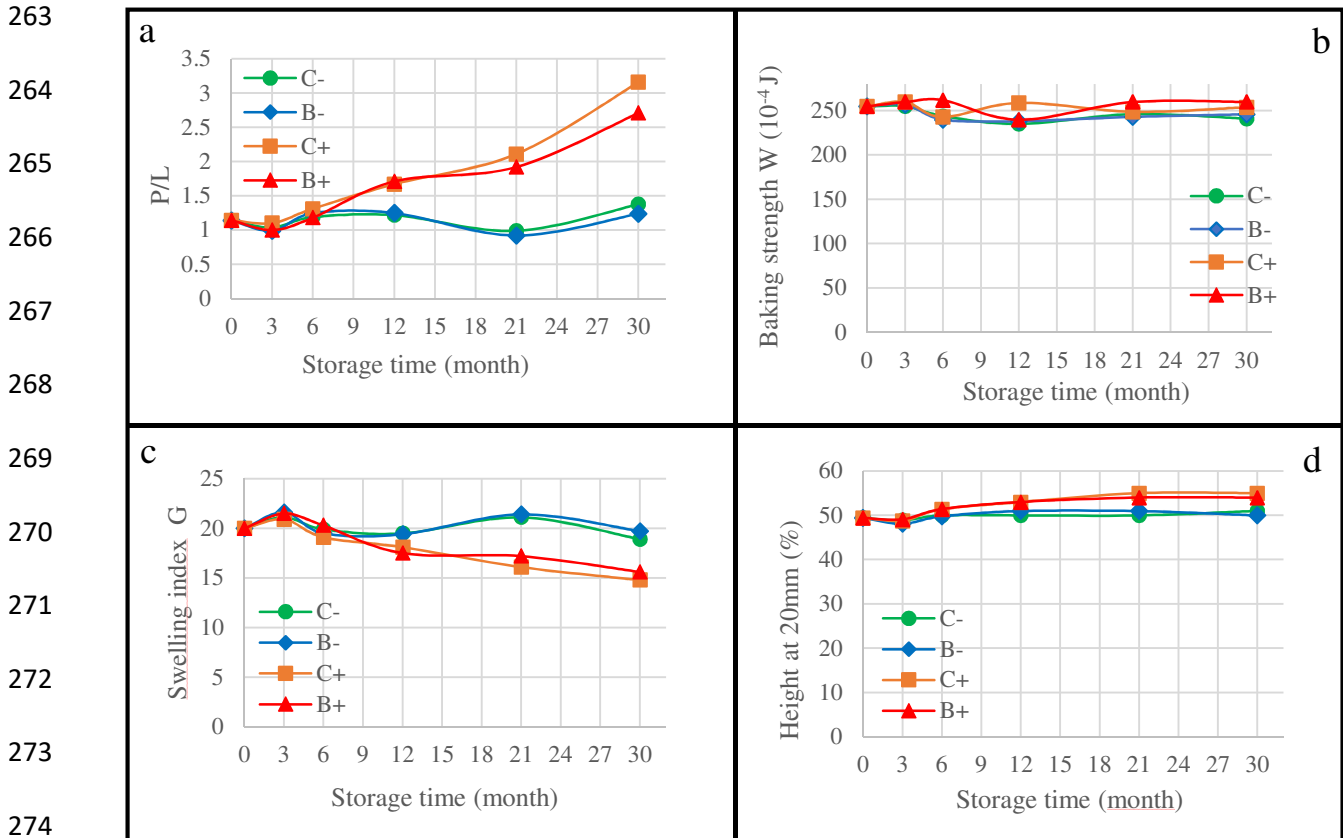
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### 254 **3.1.2. Alveograph analyses**

255

256 The initial P/L ratio was around 1 which is ideal for bread baking. It remained quite stable for  
257 the flours stored at -20 °C, whereas after 6 months, it increased considerably for the flours  
258 stored at room temperature (Figure 3 a). This means that the dough did not have the desired

259 degree of extensibility. Baking strength fluctuated noticeably but on average centred around  
 260  $250 \cdot 10^4$  J regardless of the storage condition (Figure 3 b). Logically, the Swelling index  
 261 decreased after 6 months for the flour stored at room temperature (Figure 3 c). Conversely,  
 262 the height at 20 mm increased for the flours stored at ambient temperature (Figure 3 d).



275 **Figure 3** : Alveograph analyses of flours stored in paper bags at 20 °C (B+ ▲), paper bags at -20 °C (B- ◆),  
 276 watertight containers at 20 °C (C+ ■) and watertight containers at -20 °C (C- ●) over 30 months a) P/L ratio,  
 b) Baking strength, c) Swelling index, d) Height at 20 mm

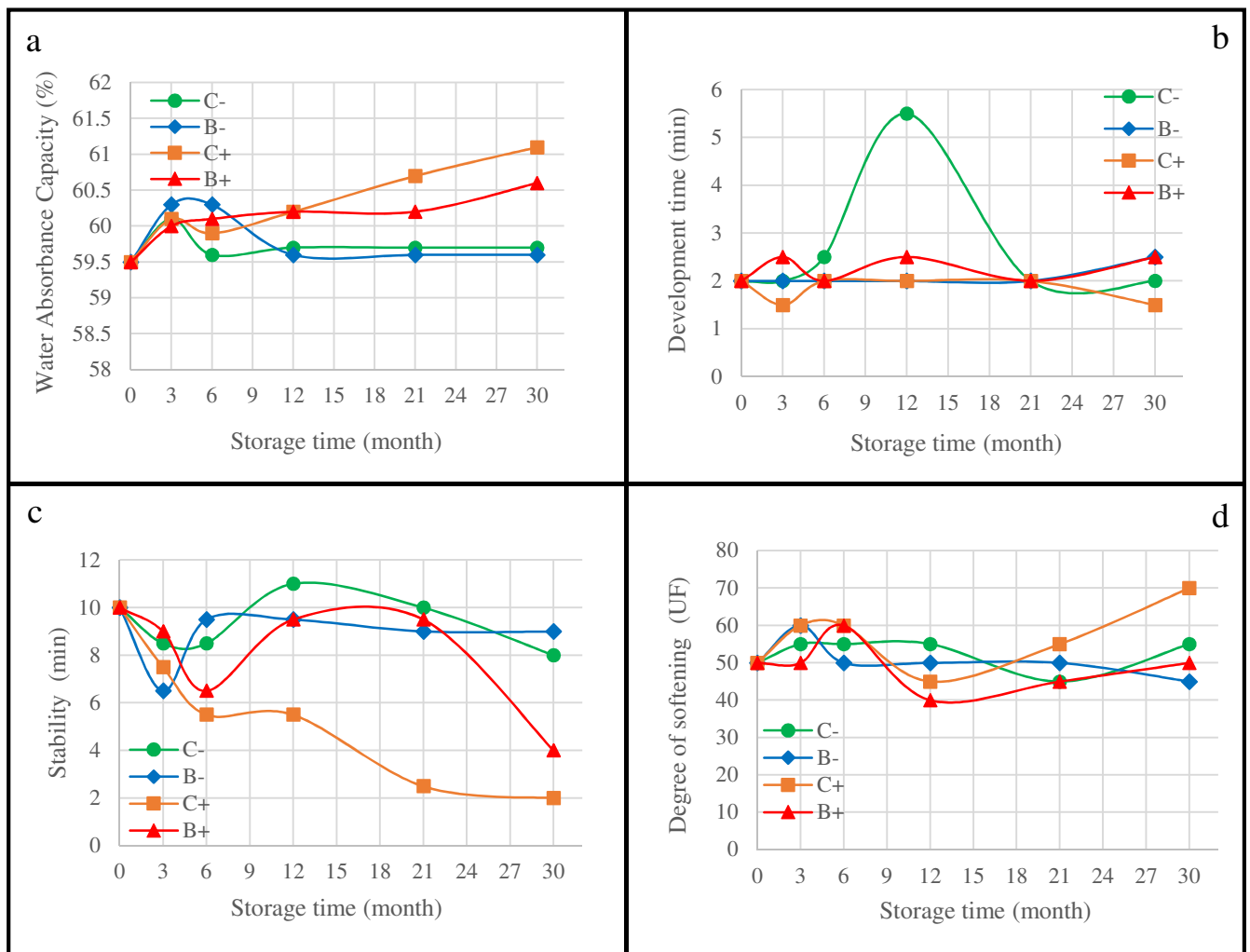
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### 278 3.1.3. Farinograph Analyses

279

280 Although the water content was quite stable in the watertight container at room temperature,  
 281 water absorption increased by more than 2.6% during the 30 months of storage (Figure 4 a).  
 282 An increase of about 1.8% was also observed for the flour bagged at ambient temperature. For  
 283 the flour stored at -20 °C, a small increase was observed at the beginning of storage but

284 finally it quickly returned to its original value. In the same way, stability decreased for the  
 285 flours stored at room temperature but was more stable for those stored at -20 °C (Figure 4 c).  
 286 The development time remained quite stable over the storage period except for the flour  
 287 stored at -20 °C in a sealed container at one year of storage (Figure 4 b).  
 288 As only one analysis was performed and the value returned to its original value afterwards,  
 289 we can consider that this point was probably an artefact. The degree of softening fluctuated  
 290 between 40 and 60 UF and increased at 70 UF for the flour stored in a watertight container at  
 291 -20 °C (Figure 4 d).



306 **Figure 4** : Farinograph analyses of flours stored in paper bag at 20 °C (B+ ▲ ), paper bag at -20 °C (B- ◆ ),  
 307 watertight container at 20 °C (C+ ■ ) and watertight container at -20 °C (C- ● ) over 30 months a) Water  
 absorbance capacity, b) Development time, c) Stability, d) Degree of softening

308 All these results suggested that bread quality should be affected for the flours stored at room  
 309 temperature.

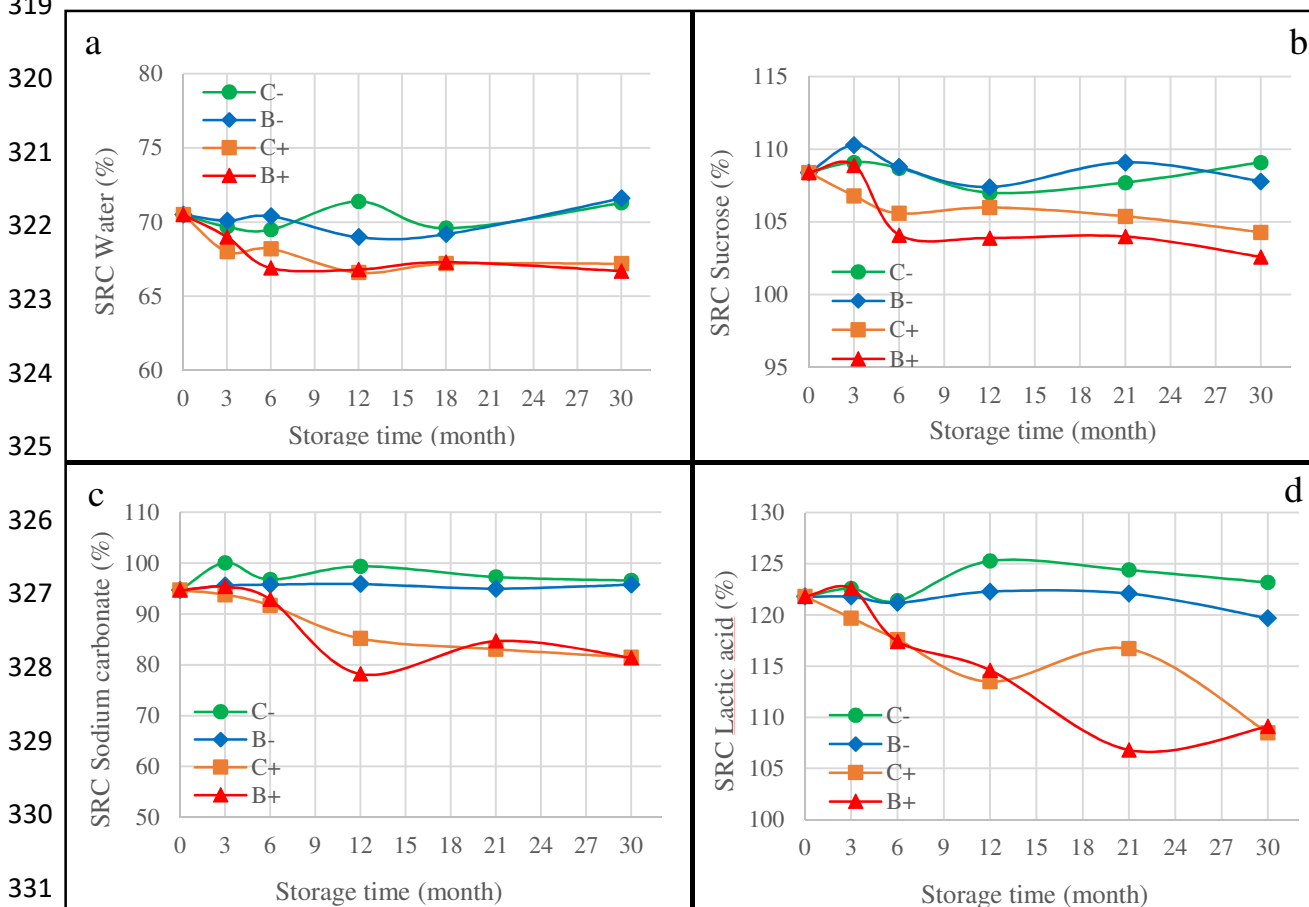
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### 311 3.1.4. Solvent Retention Capacity

312

313 As shown in Figure 5, the SRC values remained quite stable for the flours stored at -20°C  
 314 while they tended to decrease for the flours stored at room temperature. The Water Holding  
 315 Capacity of these two flours was thus substantially reduced after 30 months storage (Figure 5  
 316 a). However, the Gluten Performance Index, calculated from a ratio of the lactic acid, sodium  
 317 carbonate and sucrose SRC value, was stable over the storage period whatever the storage  
 318 condition (Figure 6). The performance of flour glutenins should be almost the same.

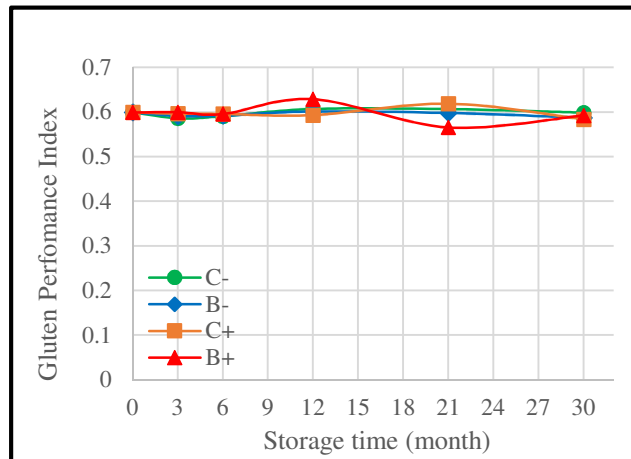
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**Figure 5:** Solvent Retention Capacity analyses of flours stored in paper bags at 20 °C (B+ ▲), paper bags at -20 °C (B- ◆), watertight containers at 20 °C (C+ ■) and watertight containers at -20 °C (C- ●) over 30 months a) Water absorbance capacity, b) Development time, c) Stability, d) Degree of softening

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*Figure 6* : Gluten Performance Index calculated for flours stored in paper bag at 20 °C (B+ ▲), paper bag at -20 °C (B- ◆), watertight container at 20 °C (C+ ■) and watertight container at -20 °C (C- ●) over 30 months

### 3.1.5. NIR analyses

PCA was applied to the set of samples composed of 60 spectra. Figure S1 a presents the score plots of the first and third components after SNV pre-treatment, explaining 86.6 % of the total variance. Figure S1 b and Figure S1 c present the first and third associated eigenvectors respectively. The samples stored in bags were clearly separated along the first axis while the samples stored in watertight containers did not seem to be affected according to this first component. The first eigenvector was characteristic of the water signal with an intense broad band around 1950 nm and a smaller one around 1430 nm (O-H), suggesting that the flour conserved in permeable bags at -20 °C absorbed water due to freezing during the first months of storage. Conversely, the flour conserved in paper bags at 20 °C seemed to dry out progressively. As expected, the quantity of water in the flour was stable in the watertight containers. The third eigenvector indicated that the samples with the longest shelf-life regardless of packaging presented a weaker signal from the starch component with bands around 1930 nm: O-H stretching and H-O-H bending from polysaccharides, 2100 nm: C=O and C-O stretching and O-H bending from polysaccharides, 2283 nm and 2324 nm: C-H



358 stretching and CH<sub>2</sub> deformation from polysaccharides, 2480 nm: C-H stretching and C-C and  
359 C-O-C stretching combination from polysaccharides.

360 The standard errors and correlation coefficients of the PLS models are shown in  
361 Supplementary Table 2. A particularly good prediction was observed for water, protein and  
362 damaged starch content, Hagberg Falling Number, P/L, Index of swelling and all SRC  
363 parameters. An acceptable prediction accuracy was obtained for ash, oleic acidity and  
364 TOTOX. Conversely, the strength and farinograph parameters did not yield satisfactory  
365 results (data not shown).

366

### 367 **3.2. Bread quality**

368

369 Power consumption curves as a function of mixing time for each storage condition are  
370 displayed in Figure S2. During the pre-mixing step, the power consumption increased only  
371 slightly. Then, during the development time, the power consumption increased more quickly  
372 to reach a maximum.

373 The doughs produced from Control, C- and B- flours were very similar. They required almost  
374 the same time to reach maximum power consumption (around 230 W), approximately 8  
375 minutes for all three. The C+ and B+ flours needed more time to reach maximum power  
376 consumption (10 minutes), with a final power lower than 200 W, indicating that these doughs  
377 were also less resistant to tool rotation. This result was consistent with the Alveograph and the  
378 Farinograph analyses.

379 After baking, the breads obtained from each flour storage condition were somewhat different  
380 in height and crumb fineness (Figure S3). The breads obtained from the flour stored in  
381 watertight containers at -20 °C were the closest to the control bread with an average number  
382 of bubbles around 1,900 and an equivalent bubble size close to 1.40 mm<sup>2</sup>, which fell within

383 the standard deviation. The breads obtained from the flour stored in paper bags at -20 °C had  
384 fewer bubbles per slice but with diameters around 1.70 mm<sup>2</sup>. On the other hand, the breads  
385 obtained from flours stored at ambient temperature presented more than 2 000 bubbles per  
386 slice with diameters smaller than 1.30 mm<sup>2</sup>.

387 Except for the breads obtained with flour stored in watertight containers at ambient  
388 temperature, the height of the bread was almost unchanged for all the other storage conditions  
389 and was consistent with those obtained for the control bread (Figure S4). These results should  
390 be compared with those obtained with the farinograph, which showed that the flour stored in  
391 the watertight container at room temperature had a high level of water absorption, a higher  
392 degree of softening and poorer stability.

393 Images of the bread slices are shown in Figure S5 in order to visually compare the fineness  
394 and size of the bubbles for the different storage conditions. Coarser gas cells were observed in  
395 control and B- slices, which exhibited the greatest similarity.

396

#### 397 **4. Conclusion**

398

399 In this study, flours were stored for 30 months to assess the impact of storage conditions on  
400 flour quality. A major outcome was that the flour stored at room temperature exhibited many  
401 more changes than the flour stored at -20 °C. Most of the analyses remained very stable over  
402 the storage period for the flours stored at -20 °C, except for the water content in the flour  
403 stored in permeable bags. Indeed, the water content in the flour progressively stabilized with  
404 atmospheric humidity, with an increase of water content of about 4% over 30 months. The  
405 water permeability of the bag was also a problem at room temperature where water loss was  
406 estimated to be close to 7%. The NIR results were consistent with these trends. The first PCA  
407 component classified the samples according to their water content in the same way. The

408 potential of the NIR technique as known from the literature and experience was confirmed for  
409 the prediction of chemical components and certain rheological parameters like P/L and the  
410 Swelling Index. Solvent Retention Capacity was also predicted with accuracy. Moreover, the  
411 results presented in this study showed that storage at room temperature greatly modifies other  
412 chemical wheat flour components. In both the paper bag and watertight container, it appeared  
413 that the flours stored at room temperature presented increased acidity and Hagberg Falling  
414 Number, strong peak oxidation during the first year of storage and a considerable decrease in  
415 Solvent Retention Capacity. This separation between the two storage conditions was also  
416 confirmed with the Farinograph and Alveograph results. Both analyses indicated poorer  
417 performance for flour stored at ambient temperature and suggested that bread quality was  
418 poorer. This point was noticeable from the mixing step. Indeed, the flours stored at room  
419 temperature required more time to reach  $t_{PEAK}$ , with lower power. After baking, it appeared  
420 that only the flour stored in the watertight container at  $-20\text{ }^{\circ}\text{C}$  retained similar bread-making  
421 properties to that of a loaf made with a recently milled flour.

422

## 423 **5. Recommendations**

424

425 The choice of suitable packaging impermeable to both oxygen and moisture, and stored in a  
426 cold room, is of utmost importance when planning long duration flour storage. It can  
427 therefore be recommended to store flour at negative temperature in sealed container in the  
428 case of storage of wheat flour 6 months. A more convenient alternative would be to store the  
429 flour at  $-20\text{ }^{\circ}\text{C}$  in paper bags, which allows also a good preservation of the initial quality of  
430 wheat flour except a partial oxidation of the flour lipids. This can be useful in the case of long  
431 term research projects for which a reference flour is needed.

432

433

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437

#### 438 **Declaration of Competing Interest**

439 The authors declare that they have no known competing financial interests or personal  
440 relationships that could have influenced the work reported in this paper.

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488 **Figure caption**

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490 Figure 1: Experimental design: Wheat Flours were packaged and stored under different  
491 conditions for up to 30 months.

492 Figure 2 : Chemical analyses of flours stored in paper bags at 20 °C (B+), paper bags at -20  
493 °C (B-), watertight containers at 20 °C (C+) and watertight containers at -20 °C (C-) over 30  
494 months. a) Protein content, b) Water content, c) Damaged starch content, d) Hagberg falling  
495 number, e) Ash content, f) Oleic acidity, h) TOTOX value.

496

497 Figure 3 : Alveograph analyses of flours stored in paper bags at 20 °C (B+), paper bags at -20  
498 °C (B-), watertight containers at 20 °C (C+) and watertight containers at -20 °C (C-) over 30  
499 months a) P/L ratio, b) Baking strength, c) Swelling index, d) Height at 20 mm.

500

501 Figure 4 : Farinograph analyses of flours stored in paper bag at 20 °C (B+), paper bag at -20  
502 °C (B-), watertight container at 20 °C (C+) and watertight container at -20 °C (C-) over 30  
503 months a) Water absorbance capacity, b) Development time, c) Stability, d) Degree of  
504 softening.

505

506 Figure 5: Solvent Retention Capacity analyses of flours stored in paper bags at 20 °C (B+),  
507 paper bags at -20 °C (B-), watertight containers at 20 °C (C+) and watertight containers at -20  
508 °C (C-) over 30 months a) Water absorbance capacity, b) Development time, c) Stability, d)  
509 Degree of softening.

510

511 Figure 6 : Gluten Performance Index calculated for flours stored in paper bag at 20 °C (B+),  
512 paper bag at -20 °C (B-), watertight container at 20 °C (C+) and watertight container at -20 °C  
513 (C-) over 30 months.