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1 **The use of potato fibre to improve bread physico-chemical properties during**
2 **storage**

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Abstract

Bread staling reduction is a very important issue for the food industry. A fiber with high water holding capacity, extracted from potato peel, was studied for its ability to reduce bread staling even if employed at low level (0.4 g fibre / 100 g flour). Physico-chemical properties (water activity, moisture content, frozen water content, amylopectin retrogradation) and ^1H Nuclear Magnetic Resonance molecular mobility were characterised in potato fibre added bread over 7 days of storage. Potato fibre addition in bread slightly affected water activity and moisture content, while increased frozen water content and resulted in a softer bread crumb, more importantly when the optimal amount of water was used in the formulation. Potato fibre also reduced ^1H NMR molecular mobility changes in bread crumb during storage. Potato fibre addition in bread contributed to reduce bread staling.

50 **1. Introduction**

51 Bread staling is a process occurring during storage of the product, that results in crumb
52 hardening, crust softening and loss of the characteristic fresh flavour of the product (Gray
53 & Bemiller, 2003). Different phenomena contribute to bread staling: starch recrystallization
54 is one of the factors contributing to crumb hardening, as well as gluten dehydration and its
55 consequent loss of plasticity, and modified gluten-starch interactions. Water plays a
56 fundamental role in bread staling and, hence, the study of water status and its dynamics is
57 very important to better understand the bread staling phenomenon. Water migrates from
58 crumb to crust at a macroscopic level and redistributes at a molecular level, becoming
59 partially incorporated in starch crystals, loses phase separating capability (decreased
60 “DSC freezable water” content) and is redistributed among bread domains (Baik &
61 Chinachoti, 2001; Curti, Carini, Tribuzio, & Vittadini, 2014; Schiraldi & Fessas, 2001; Slade
62 & Levine, 1991; Vittadini & Vodovotz, 2003).

63 Addition of large amounts of fibre into bread to produce high fibre products has been
64 object of much research in an effort to improve customers’ fiber intake but it is often
65 detrimental to bread quality (Chen, Rubenthaler, Leung, & Baranowski, 1988; Katina,
66 Salmenkallio-Marttila Partanen, Forssell, & Autio, 2006). Large amounts of fibre are known
67 to negatively modify dough and bread properties, production process, and staling-related
68 phenomena (e.g. gluten dehydration, amorphous starch recrystallization, water molecular
69 redistribution among bread components; Collar, Santos & Rosell, 2007; Fadda,
70 Sanguinetti, Del Caro, Collar & Piga, 2014; Gray & Bemiller, 2003). However, with the
71 selection of the proper type of fibre and proper technological fibre treatment, fibre addition
72 can improve bread properties and retard staling (Laurikainen, Harkonen, Autio, &
73 Poutanen, 1998; Sangnark & Noomhorm, 2003; Sangnark & Noomhorm, 2004; Wang,
74 Rosell & Benedito de Barber, 2002).

Potato peel, a by-product from the potato industry, has been reported to be a very rich (higher than wheat bran) and good source of fibre with high water-holding capacity (Camire & Flint, 1991; Camire, Violette, Dougherty & McLaughlin, 1997).

Few works considered the effect of potato peel as a source of fibre in bread (Toma, Orr, D'Appolonia, Dintzis, & Tabekhia, 1979) and cakes (Sharoba, Farrag, & El-Salam, 2013), reporting higher farinograph absorptions, reduced gas retention and volumes, as well as increased hardness in the products. In all these reports potato peel was added in large amounts (5-20%) to bread formulations in an effort to increase bread fibre content. Based on its characteristics and properties, potato fibre may also have an effect on water status and dynamics, possibly retarding and modulating bread staling.

The aim of the present work is to investigate a potential technological use of potato fibre in improving bread physico-chemical properties and reduce bread staling. Potato fibre was, therefore, added in small amount into a bread formulation, and its effect on physico-chemical properties and water status of the product was studied during storage.

2. Materials and methods

2.1. Bread formulation, production and storage

Three breads were produced. The control sample was named STD and it was produced with optimal water amount (500 Brabender Units). The formulations [wheat flour (Molino Seragni, Cremona, Italy); sugar (Coprob S.C.A, Pavia, Italy); salt, (Italkali s.p.a., Palermo, Italy); yeast (AB Mauri Italy s.p.a, Padova, Italy); sunflower seeds oil (Oleificio Zucchi, Cremona, Italy)] are reported in Table 1.

Potato fibre (HI-FIBRE 115, HI-FOOD S.p.a. Collecchio, Italy), extracted from the potato peel and very rich in soluble components, was added to the formulation at 0.4% on a flour basis (g fibre/ 100 g flour) to produce two samples, P-W and P-STD. The water absorption used for P-W was increased of 4%, according to preliminary trials aiming at identify the conditions (fibre and water level) to obtain an optimized final product in terms of volume,

101 colour, and texture. P-STD was produced with the same amount of water used for STD to
102 clearly highlight the effect of fiber. Potato fibre composition (as indicated by the producer)
103 was as follows: ~ 6.0% (g / 100 g fiber) moisture, protein < 1.0 %, fat < 1.0%,
104 carbohydrates < 1.0 %, dietary fiber ~ 92.0 % (soluble fiber ~ 73.0 %; insoluble fiber ~ 19.0
105 %), ashes ~ 2.0 %.

106 Breads were produced with a home bread-maker (Backmeister 68511, UNOLD, Germany)
107 using a “basic” program (pre-heating 17 min; first kneading 5 min; second kneading 13
108 min; first fermentation 45 min; smoothing 1 min; second fermentation 18 min; smoothing 1
109 min; third fermentation 45 min; baking 55 min), cooled to room temperature, placed in
110 polyethylene bags sprinkled with about 3 ml ethanol, and stored at room temperature.
111 Samples (three loaves for each sample for each storage time) were analyzed fresh (day 0)
112 and after 1, 3, 5 and 7 days of storage.

113 *2.2. Volume and texture*

114 Volume was measured on three bread loaves for each sample following the American
115 Association Cereal Chemistry 10-05 method (Guidelines for Measurement of Volume by
116 Rapeseed Displacement).

117 Bread crumb hardness was measured with a TA.TX2 Texture Analyzer (Stable Micro
118 Systems, Goldalming, UK). At least eight cubic portions ($2 \times 2 \times 2 \text{ cm}^3$) of crumb were
119 extracted from the central slices of the bread loaf and compressed (force = 0.1 N) to 40%
120 deformation using a cylindrical probe (P/35 Dia Cylinder Aluminium). Crumb texture was
121 described in terms of Hardness (maximum height of the first compression peak) and
122 Cohesiveness (ratio of the areas of the second to the first compression peak).

123 *2.3. Water activity and moisture content*

124 Water activity of crumb (from loaf centre) and crust was measured with a dew point
125 instrument (Aqualab 4TE, Decagon Devices, WA, USA). At least five measurements were
126 taken for each sample. Moisture content (MC) of crumb (from loaf centre) and crust were

determined in triplicate for each bread loaf by weight loss at 105°C (NSV 9035, ISCO, Milan, Italy) to constant weight.

2.4. Frozen water content and retrograded amylopectin

Crumb thermal properties were measured with a Differential Scanning Calorimeter (DSC Q100 TA Instruments, New Castle, DE, USA), calibrated with indium and mercury. Bread crumb (4 g, from loaf centre) was properly compressed to obtain a flat and compact crumb sample to maximize heat transfer within the DSC cell during the experiment. Samples (5-10 mg) were taken and placed in stainless steel pans (Perkin Elmer, USA) that were then hermetically sealed, quench cooled to -80°C and heated at 5°C/min to 130°C. DSC thermograms were analysed (Universal Analysis Software 3.9A, TA Instruments, New Castle, DE). “Frozen” water (at the given experimental conditions; FW) was calculated from the endothermic peak around 0°C (ice melting) using the following equation:

$$FW = \text{Enthalpy Ice Fusion} \times \left(\frac{1}{\text{latent heat ice fusion}} \right) \times \left(\frac{1}{MC} \right) \times 100$$

Where FW is Frozen water at the given experimental conditions (g frozen water/100 g water), Enthalpy Ice Fusion (J / g product), Latent heat of ice fusion is 334 J / g ice and MC is Moisture Content (g water/ g product).

Retrograded amylopectin (J/g sample) was obtained by the integration of the endothermic peak in the 50-80°C temperature range.

2.5. Molecular mobility (¹H NMR)

A low resolution (20 MHz) ¹H NMR spectrometer (the MiniSpec, Bruker Biospin, Milano, Italy) operating at 25.0 ± 0.1 °C was used to measure the Free Induction Decay (FID) and the transverse (T₂) relaxation times of the samples. Crumb samples (10 mm high) were prepared in 10 mm NMR tube, sealed with Parafilm® to prevent moisture loss during the NMR experiment.

151 FIDs were acquired using a single 90° pulse, followed by a dwell time of 7 μs, 32 scans
152 and a recycle delay of 3 s and a 10 ms acquisition window. ¹H FIDs were analyzed in the
153 time range 7 μs -100 μs where the homogeneity of magnetic field was assured. Fitting of
154 FID was carried out with a two components model (exponential and gaussian, LeBotlan &
155 Helie-Fourel, 1995; Sigmaplot, v6, Systat Software Inc. USA):

156
$$I(t) = y_0 + A * \exp[-(t / T_A)] + B * \exp[-(t / T_B)^2]$$

157 where y₀ is the FID decay offset, A and B are the are intensities of each relaxation
158 component, T_A and T_B are the apparent relaxation times.

159 T₂ relaxation times were measured with a CPMG pulse sequence with a recycle delay of 3
160 s (≥ 5 ¹H T₁), an interpulse spacing of 0.04 ms and 4000 data points. Quasi-continuous
161 distributions of relaxation times were obtained from the experimental T₂ curves using a
162 UPENWin software (Alma Mater Studiorum, Bologna, Italy). Default values for all UPEN
163 parameters were used with the exception of one (LoXtrap) that was set to 1 to avoid
164 extrapolation of relaxation times shorter than the first experimental point.

165 *2.6. Statistical analysis*

166 One-way-analysis of variance (ANOVA, SPSS v.20, IBM, NJ, USA), followed by least
167 significant difference test (LSD) at p ≤ 0.05, was used to verify significant differences of
168 evaluated parameters of the same sample during storage and among the samples at the
169 same storage time.

170 **3. Results and discussion**

171 *3.1. Water activity and moisture content*

172 Crumb and crust water activity and moisture content of samples are shown in Table 2.

173 Crust water activity (Figure 1a) was significantly different in the fresh breads: it was
174 significantly higher in P-W (~0.80) than in P-STD (~0.74) but statistically not different to
175 STD (~0.78). Crust water activity increased during storage in all samples, due to moisture
176 migration from crumb to crust.

177 Crumb water activity (Figure 1a) at day 0 showed very slight statistical differences (STD
178 and P-STD: ~ 0.96 , P-W: ~ 0.97), and samples were, therefore, considered not different for
179 this parameter. Crumb water activity generally decreased during storage without important
180 changes in all samples, at day 7 P-STD had a water activity slightly lower than STD and P-
181 W.

182 Crust moisture content was significantly higher in potato fibre added breads ($\sim 15\%$, g
183 water/100 g sample) as compared to STD ($\sim 13\%$), increased during storage in all
184 samples, and was not statistically different at the end of storage (Figure 1b). Crumb
185 moisture content of fresh breads was only slightly higher in P-W and STD ($\sim 41\%$) than in
186 P-STD ($\sim 39\%$), as previously reported for other fibres (Dalgetty, & Baik, 2006).

187 Crumb moisture content significantly decreased in all samples, as a consequence of the
188 macroscopic migration of water from the wetter crumb to the drier crust. However, this
189 decrease was limited due to the fact that crumb represented, weight wise, the majority of
190 the bread loaf and crust only a small portion. Moreover most of the water migrating from
191 the crumb to the crust would come from the portion of crumb closer to the crust. At the end
192 of storage STD ($\sim 39\%$) and P-W ($\sim 40\%$) had significantly larger crumb moisture content
193 as compared to P-STD ($\sim 37\%$).

194 3.2. Crumb texture

195 All bread samples (STD, P-STD and P-W) had comparable loaves volume (data not
196 shown).

197 Hardness and cohesiveness of bread crumbs during storage are shown in Figure 1a and
198 1b. Crumb hardness was comparable in fresh samples, and it significantly increased in all
199 products during storage, as expected. Crumb hardness of STD and P-STD increased
200 more pronouncedly during storage than in P-W. P-W was the softest bread ($\sim 2.6 \pm 0.6$ N),
201 followed by P-STD ($\sim 3.7 \pm 0.6$ N) and STD ($\sim 4.5 \pm 0.7$ N) at the end of storage. Only slight
202 differences in MC were observed in the 7-days old STD and P-W, hence the improved

203 texture observed in P-W was not relatable to MC. Cohesiveness was comparable in fresh
204 samples and decreased similarly in all samples during storage.

205 Previous works investigated bread formulations where soluble fibre was added in limited
206 amounts (1-5%) with the aim to improve bread properties. Soluble fibre has been reported
207 to increase crumb firmness and amylopectin retrogradation, at moisture contents larger
208 than in the control sample (Gómez, Ronda, Blanco, Caballero, & Apesteguía, 2003;
209 Skendi, Biliaderis, Papageorgiou, & Izydorczyk, 2010; Zhou et al., 2009). In our samples,
210 softer crumb was observed also in absence of larger MC (P-STD), suggesting that the high
211 water holding capacity of the potato fibre may have positively influence the texture of the
212 product.

213 3.3. *Thermal analysis*

214 Thermograms of fresh bread crumbs (from -80 to 130°C, data not shown) showed a major
215 endothermic peak around 0°C and, in stored samples a second minor endothermic event
216 occurring at higher temperatures (50–80°C). The major DSC peak around 0°C was
217 attributed to ice melting and the relative enthalpy was used to calculate the frozen water
218 content (FW%) of samples (Table 2).

219 At day 0 FW was significantly larger in P-W ($\sim 57 \pm 5$ %, g frozen water / 100 g water) and
220 P-STD ($\sim 61 \pm 4$ %), than in STD ($\sim 51 \pm 4$ %), indicating that, with very slight differences in
221 the MC, the availability of water, as measured by DSC, was influenced by the presence of
222 potato fibre, that possibly acted on water-solids interactions (as observed in this time-
223 frame experimental window). FW significantly decreased in all samples, to $\sim 55\%$, $\sim 52\%$
224 and $\sim 47\%$ in P-W, P-STD and STD, respectively, as previously reported (Ribotta & Le Bail,
225 2007). The differences observed in macroscopic water parameters (MC and FW) indicated
226 that water molecules interacted more loosely in the bread matrix in the presence of potato
227 fibre (P-W and P-STD), suggesting that potato fibre enhanced water macromolecular
228 mobility (Curti, Carini, Bonacini, Tribuzio, & Vittadini, 2013).

229 The endothermic peak (50-80°C temperature range) observed in the thermograms of
230 stored bread crumb was attributed to recrystallised amylopectin melting (Baik &
231 Chinachoti, 2000; Russell, 1983). No endothermic peak was observed in the fresh and 1-
232 day stored samples while at longer storage times the peak became increasingly larger
233 (Figure 1c). Recrystallised amylopectin at day 7 was comparable among the samples (1.7
234 ± 0.2 , $\sim 1.5 \pm 0.1$ and $\sim 1.5 \pm 0.4$ J/g sample, in STD, P-W and P-STD respectively)
235 indicating that potato fibre had no particular influence on amylopectin retrogradation,
236 despite its high water holding capacity, as previously reported in soluble fibre enriched
237 bread (Dalgetti & Baik, 2006; Skendi, Biliaderis, Papageorgiou, & Izydorczyk, 2010). Softer
238 crumbs in P-W and P-STD were not related to retrograded amylopectin (that was
239 comparable) and MC (lower in P-STD as compared to P-W), while it might be associated
240 to a stronger water retention of potato fibre and an 'higher water availability' as suggested
241 by the larger FW.

242 3.4. Molecular mobility

243 Molecular mobility characterization was carried out for, the fastest-relaxing ^1H
244 components, with a ^1H FID NMR experiment, while slower relaxing protons were
245 characterised in terms of ^1H T_2 relaxation times distributions.

246 Representative ^1H FIDs of bread object of this study are reported in Figure 2a. At day 0 ^1H
247 FIDs of STD and P-STD were sharper than in P-W, despite their comparable MC,
248 suggesting an increased molecular mobility in this sample. During storage all ^1H FIDs
249 increased their steepness as previously reported in bread (Curti et al., 2014; Sereno, Hill,
250 Mitchell, Scharf, & Farhat, 2007), due to moisture loss from the crumb and increasing
251 recrystallised amylopectin content. At day 7, ^1H FID were comparable in STD and P-W,
252 while P-STD still showed the steepest decay.

253 ^1H FID curves were fitted with a two components model (exponential and Gaussian
254 function; Figure 2b and 2c) to obtain quantitative information about the relaxation time and

percentage of protons belonging to the more rigid and more mobile proton populations detectable within the FID experimental time-frame. In fresh breads, the more rigid component (population A, relaxing at 0.016-0.018 ms, T_A) represented ~16-17% of the total protons in STD and P-W while it was larger (~20%) in P-STD although with comparable relaxation time, indicating a reduced molecular mobility in this sample. The more mobile component (population B, relaxing at 1.5-2.0 ms, T_B) was, specularly, less represented in P-STD than in STD and P-W. T_A and T_B relaxation times remained constant during storage while the amount of protons belonging to population A increased in all samples with increasing storage time, indicating an increasing molecular rigidity of bread crumb. At the end of storage P-STD was the product with a larger degree of rigidity, as its population A increased to ~36%, while it represented only ~30% of the protons of P-W and STD.

The presence of two proton populations in ^1H FID was previously reported model systems (heated dough) and bread (Bosmans, et al., 2012): the fastest relaxing protons were associated to the protons of crystalline and amorphous starch not in contact with water and to protons of amorphous starch and gluten in little contact with water, respectively. The differences observed at day 7 in the ^1H FID populations of the breads object of this study appeared not to be attributable to both moisture content loss and amylopectin retrogradation (that was comparable), as previously reported (Farhat, Ottenhof, Marie, & De Bezenac, 2003; Sereno et al., 2007), but only to the different moisture contents.

A representative ^1H T_2 distribution is shown in Figure 3a. Three ^1H T_2 protons populations were observed in all samples and they were named starting from the shortest to the longest relaxation time C, D and E, respectively (Figure 3b and 3c). The overall shape of the ^1H T_2 relaxation time distributions did not change in all samples during storage. Population C represented protons relaxing at ~ 0.5 ms (T_{2C}), population D protons relaxed at ~ 9-11 ms (T_{2D}) while population E protons were characterised by relaxation times of

about 130 ms (T_{2E} ; Figure 3b). Comparable relaxation times were found among all fresh samples. In STD, population C encompassed ~ 29% of total protons, population D ~ 66 %, and population E ~ 5%. P-STD showed a comparable (~30%) presence, to STD, of the more rigid protons while these protons were less abundant in P-W (~26%) (Figure 3c). On the contrary, a smaller presence of protons belonging to population D was observed in P-STD (~65%) than in P-W (~70%). No significant changes in mobility of populations C and E were detected (comparable T_{2C} and T_{2E} at all storage times) during storage in all samples, while population D shifted towards shorter relaxation times (T_{2D} significantly decreased to ~ 6-8 ms) in all samples (Figure 3b and 3c). Protons population abundances showed slight changes in STD, where population C decreased to ~26% and population D increased to ~69% (Figure 3b and 3c) during 7 days of storage.

Previous studies reported the presence of multiple proton populations in white bread. Changes in proton mobility have been related to macroscopic and mesoscopic staling phenomena, such as water migration, starch recrystallization and crumb firming. In particular increasing rigidity (larger amount in the FID fast relaxing protons and T_2 population D) has been attributed to water loss, starch crystals formation, gluten dehydration (Bosmans et al., 2012; Bosmans, Lagrain, Ooms, Fierens, & Delcour, 2013; Engelsen et al., 2001; Sereno et al., 2007; Wang, Choi, & Kerr, 2004).

It was hypothesised that potato fibre, especially when the optimum water amount was used in the formulation (P-W), contributed to reduce molecular mobility changes during storage, possibly limiting crumb firming.

4. Conclusions

Potato fibre (extracted from potato peel) was found to have an important effect, when added in limited amounts (0.4%), on bread properties during storage. Texture of the products was improved (bread was softer), in particular when the optimum amount of water was used in the bread formulation (P-W). The addition of potato fibre slightly

307 affected water parameters, in terms of water activity and moisture content. DSC analysis
308 showed a larger presence of frozen water and reduced retrograded amylopectin in potato
309 fibre added breads. ^1H NMR mobility was affected by the presence of potato fibre: the fast-
310 relaxing protons (^1H FID population A and ^1H T_2 population C) were less represented in the
311 bread produced with the optimal water amount, indicating a decreased rigidity, that was
312 maintained during storage.

313 Potato fibre improved the texture of bread, possibly by a retention of water allowing for the
314 maintenance of a softer crumb texture during storage.

315 More information should be collected to better understand the nature of potato fibre
316 interactions with other bread components (e.g. starch). The effect of higher amounts of
317 potato fibre on bread staling could also be considered, to evaluate the optimal level of
318 addition that represents the compromise between technological and sensory quality. The
319 implementation of potato fiber addition at industrial level should be in last instance carried
320 out.

321

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325

326 **References**

327 AACC International. Approved methods of analysis, 11th ed. Method 10-05.01.
328 Guidelines for measurement of volume by rapeseed displacement. October 3, 2001. St.
329 Paul, MN, U.S.A.: AACC International. <http://dx.doi:10.1094/AACCIntMethod-10-05.01>.

330 Baik, M.Y., & Chinachoti, P. (2000). Moisture redistribution and phase transitions
331 during bread staling. *Cereal Chemistry*, 77, 484-488.

332 Baik, M.Y., & Chinachoti, P. (2001). Effects of glycerol and moisture gradient on
 333 thermo-mechanical properties of white bread. *Journal of Agricultural and Food*
 334 *Chemistry*, 49, 4031–4038.

335 Bosmans, G. M., Lagrain, B., Deleu, L. J., Fierens, E., Hills, B. P., & Delcour, J. A.
 336 (2012). Assignments of Proton Populations in Dough and Bread Using NMR
 337 Relaxometry of Starch, Gluten, and Flour Model Systems. *Journal of Agricultural of*
 338 *Food Chemistry*, 60, 5461-5470.

339 Bosmans, G. M., Lagrain, B., Ooms, N., Fierens, E., & Delcour, J. A. (2013).
 340 Biopolymer interactions, water dynamics and bread crumb firming. *Journal of*
 341 *Agricultural and Food Chemistry*, 61, 4646-4654.

342 Camire, M. E., & Flint, S. I. (1991). Thermal processing effects on dietary fibre
 343 composition and hydration capacity in corn meal, oatmeal and potato peels. *Cereal*
 344 *Chemistry*, 68, 645-647.

345 Camire, M. E., Violette, D., Dougherty, M. P., & McLaughlin, M. A. (1997). Potato peel
 346 dietary fiber composition: effects of peeling and extrusion cooking processes. *Journal*
 347 *of Agricultural and Food Chemistry*, 45, 1404-1408.

348 Chen, H., Rubenthaler, G.L., Leung, H.K., & Baranowski, J.D. (1988) Chemical,
 349 physical, and baking properties of apple fibre compared with wheat and oat bran.
 350 *Cereal Chemistry*, 65, 244–247.

351 Collar, C., Santos, E., & Rosell, C.M. (2007). Assessment of the rheological profile of
 352 fibre-enriched bread doughs by response surface methodology. *Journal of Food*
 353 *Engineering*, 78, 820–826.

354 Curti, E., Carini, E., Bonacini, G., Tribuzio, G., & Vittadini, E. (2013). Effect of the
 355 addition of bran fractions on bread properties. *Journal of Cereal Science*, 57(3), 325-
 356 332.

357 Curti, E., Carini, E., Tribuzio, G., & Vittadini, E. (2014). Bread staling: Effect of gluten
 358 on physico-chemical properties and molecular mobility. *LWT-Food Science and*
 359 *Technology*, 59, 418–425.

360 Dalgetty, D. D., & Baik, B. K. (2006). Fortification of bread with hulls and cotyledon
 361 fibers isolated from peas, lentils, and chickpeas. *Cereal Chemistry*, 83, 269-274.

362 Engelsen, S.B., Jensen, M.K., Pedersen, H.T., Norgaard, L., & Munck, L. (2001). NMR-
 363 baking and multivariate prediction of instrumental texture parameters in bread. *Journal*
 364 *of Cereal Science*, 33, 59-67.

365 Fadda, C., Sanguinetti, A. M., Del Caro, A., Collar, C., & Piga, A. (2014). Bread Staling:
 366 Updating the View. *Comprehensive Reviews in Food Science and Food Safety*, 13,
 367 473-492.

368 Farhat, I.A., Ottenhof, M.A., Marie, V., & De Bezenac, E. (2003). ¹H NMR relaxation
 369 study of amylopectin retrogradation. In P.S. Belton, A.M. Gil, G.A. Webb, D. Rutledge
 370 (Eds), *Magnetic Resonance in food science: latest developments* (pp. 172-179). UK:
 371 RSC Publishing.

372 Gómez, M., Ronda, F., Blanco, C. A., Caballero, P. A., & Apesteguía, A. (2003). Effect
 373 of dietary fibre on dough rheology and bread quality. *European Food Research and*
 374 *Technology*, 216, 51-56.

375 Gray, J. A., & Bemiller, J. N. (2003). Bread Staling: Molecular Basis and Control.
 376 *Comprehensive Reviews in Food Science and Food Safety*, 2, 1-21.

377 Katina, K., Salmenkallio-Marttila, M., Partanen, R., Forssell, P. & Autio, K. (2006).
 378 Effects of sourdough and enzymes on staling of high-fibre wheat bread. *LWT – Food*
 379 *Science and Technology*, 39, 479–491.

380 Laurikainen, T., Harkonen, H., Autio, K., & Poutanen, K. (1998). Effects of enzymes in
 381 fiber-enriched baking. *Journal of the Science of Food and Agriculture*, 76, 239–249.

382 Le Botlan, D. & Helie-Fourel, I. (1995). Assessment of the intermediate phase in milk
 383 fat by low-resolution nuclear magnetic resonance. *Analytica chimica acta*, 311, 217-
 384 223.

385 Russell, P.L. (1983). A kinetic study of bread staling by differential scanning calorimetry
 386 and compressibility measurements. Effect of different grits. *Journal of Cereal Science*,
 387 1, 285–286.

388 Sangnark, A., Noomhorm, A. (2003). Effect of particle sizes on functional properties of
 389 dietary fibre prepared from sugarcane bagasse. *Food Chemistry*, 80, 221–229.

390 Sangnark, A., & Noomhorm, A. (2004). Chemical, physical and baking properties of
 391 dietary fiber prepared from rice straw. *Food Research International*, 37, 66-74.

392 Schiraldi, A., & Fessas, D. (2001). Mechanism of staling: an overview In: P. Chinachoti,
 393 Y. Vodovotz (Eds.), *Bread Staling* (pp. 1–17). New York: CRC press.

394 Sereno, N.M., Hill, S.E., Mitchell, J.R., Scharf, U., & Farhat, I. A. (2007). Probing
 395 water migration and mobility during the aging of bread. In: I.A. Farhat, P.S. Belton,
 396 and G.A. Webb, (Eds), *Magnetic Resonance in Food Science: From Molecules to*
 397 *Man* (pp. 89-95). UK: RSC Publishing.

398 Sharoba, A. M., Farrag, M. A., & El-Salam, A. A. (2013) Utilization of some fruits and
 399 vegetables wastes as a source of dietary fibers in cake making. *Journal of Food and*
 400 *Dairy Sciences*, 4, 433 – 453.

401 Skendi, A., Biliaderis, C.G., Papageorgiou, M., & Izydorczyk, M.S. (2010). Effects of
 402 two barley β -glucan isolates on wheat flour dough and bread properties. *Food*
 403 *Chemistry*, 119, 1159-1167.

404 Slade, L., & Levine, H. (1991). Beyond water activity: Recent advances based on an
 405 alternative approach to assessment of food quality and safety, *Critical Reviews in Food*
 406 *Science and Nutrition*, 30, 115–360.

Toma, R. B., Orr, P. H., D'Appolonia, B., Dintzis, F. R., & Tabekhia, M. M. (1979). Physical and chemical properties of potato peel as a source of dietary fiber in bread. *Journal of Food Science*, 44, 1403-1407.

Vittadini, E., & Vodovotz, Y. (2003). Changes in the physicochemical properties of wheat-and-soy-containing breads during storage as studied by thermal analyses, *Journal of Food Science*, 68, 2022-2027.

Wang, J., Rosell, M.C., & Barber, C.B. (2002). Effect of the addition of different fibers on wheat dough performance and bread quality. *Food Chemistry*, 79, 221–226.

Wang, X., Choi, S.G., & Kerr, W.L. (2004). Water dynamics in white bread and starch gels as affected by water and gluten content. *LWT—Food Science and Technology*, 37, 377-384.

Zhou, Y., Wang, D., Wan, X., Zhang, L., Du, X., & Hu, W. (2009). Effect of tea polysaccharide addition on the properties of bread made from two flours. *Journal of Food Processing and Preservation*, 33, 798-813.

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434

435 **Figure Captions**

436 **Fig.1.** Hardness (a), Cohesiveness (b) and Amylopectin retrogradation (c) of STD (black),
437 P-W (white) and P-STD (grey) during storage^a

438

439 **Fig.2.** Representative ¹H FIDs (a) of STD (black), P-W (white) and P-STD (grey) at day 0
440 (circles) and day 7 of storage (squares); ¹H FID relaxation times (b) and populations (c) of
441 STD (black), P-W (white) and P-STD (grey) during storage.

442

443 **Fig. 3.** Representative ¹H T₂ relaxation time distribution of samples (a); ¹H T₂ relaxation
444 times (b) and populations (c) of STD (black), P-W (white) and P-STD (grey) during
445 storage.

^aStatistical significance: small letters indicate significant differences among samples with the same formulation at different storage times; capital letters indicate significant differences among samples with different formulation at the same storage time; n.d. Not detectable; (-) No significant difference)