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► **To cite this version:**

Nesrin Hesso, Alessandra Marti, Patricia Le-Bail, Catherine Loisel, S. Chevallier, et al.. Conformational changes of polymers in model batter systems. *Food Hydrocolloids*, 2015, 51, pp.101-107. 10.1016/j.foodhyd.2015.05.010 . hal-02520106v2

**HAL Id: hal-02520106**

**<https://hal.science/hal-02520106v2>**

Submitted on 24 Jul 2024

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1 **Conformational changes of polymers in model batter systems**

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26 **Abstract**

27 Cake batters - made of flour, egg, sugar and fat - are complex systems. Ingredients  
28 interactions and their impact on protein secondary structure and starch conformational  
29 structures were studied in model batter systems using Attenuated Total Reflectance Fourier  
30 Transform Infrared (ATR-FTIR) spectroscopy. The results showed the possibility of using the  
31 pregelatinized starch ~~for improving the texture of the cake~~ without affecting protein  
32 conformation. The estimation of protein secondary structure highlighted the prevalence of  $\alpha$ -  
33 helical structures in the model batter system, while  $\beta$ -sheets are predominant in flour systems  
34 as known in dough systems. The protein conformation in batter system are related to fat-  
35 protein interactions and could explain fat functionality in the final product. Starch crystallinity  
36 increased when each ingredient - except for pregelatinized starches - was added to the flour.  
37 Changes in starch conformation could be related to the redistribution of water between the  
38 batter ingredients. The overall results highlighted the importance of ingredients on the  
39 structural conformation of the batter polymers - starch and proteins - which could be the key  
40 factor to understand the functional properties of the batter.

41

42 **Keywords:** cake batter; pregelatinized starch; protein secondary structure; starch structure;  
43 ATR-FTIR spectroscopy  
44

## 45 **1. Introduction**

46           Quality control has become a highly important topic in food industry. The quality of  
47 cakes depends on the balanced formulas, aeration of cake batters, stability of fluid batters in  
48 the early stage of baking, and thermal-setting stage (Gomez et al., 2007). In addition,  
49 macromolecular interactions are highly considered to influence the baked-products quality  
50 (Bruun, 2006). Cakes - as all baking products - are basically composed of molecular and  
51 colloid dispersions of biopolymers and their complexes (Bennion & Bamford, 1997). Starch  
52 and protein - the major two biopolymers - are fundamental to the structure, rheology, and  
53 other physical properties, as well as the sensory perception of these products. Water and  
54 lipids, bound to other components or acting as solvents, are important factors as well (Bruun,  
55 2006).

56           Starch represents an important constituent acting in two ways: during batter mixing,  
57 starch with the other components of flour hinders fat coalescence by increasing the viscosity  
58 of the aqueous phase (Shepherd & Yoell, 1976), while during baking starch is responsible for  
59 the transformation of an aqueous, fluid batter into a solid, porous cake structure (Donovan,  
60 1977). As regards gluten, full development of gluten into a continuous visco-elastic structure  
61 such as it occurs in bread making does not happen in cakes due to the formulations and  
62 mixing procedures (Donelson & Wilson, 1960). Although the development of a gluten  
63 network is limited in cake batter, gluten proteins may become important for cake structure  
64 during baking (Wilderjans et al., 2008).

65           Egg proteins, during mixing, are responsible for the formation of a stable emulsion  
66 (Wilderjans et al., 2013). Mine (2002) assumed that yolk proteins adsorb at the oil-water  
67 interface in the cake batter which contributes to film formation that stabilizes the fat  
68 coalescence.

69           Fats retain the gas cells at room temperature during mixing, making them immobile  
70 and hence stable (Delcour & Hoskeney, 2010). These gas cells are then used as nuclei during  
71 cake baking.

72 Sugar has an abrasive effect on the fat and promotes the breakdown of crystal  
73 aggregates during mixing into smaller size crystals which are the most effective for air  
74 incorporation (Shepherd & Yoell, 1976). It also competes with gluten proteins for water,  
75 promoting a weaker gluten development (Donelson & Wilson, 1960).

76 Finally, recently it was demonstrated that adding pregelatinized starch improves cake  
77 softness and softness retaining during storage (Sozer et al., 2011, Hesso et al., 2014).

78 From the above, it is clear that the cake batter functional properties reflect the  
79 physico-chemical properties of both the complexed and the individual macromolecules,  
80 which contribute to the diversity of structures (Bruun, 2006). One way to understand these  
81 functionalities is to study the chemical interactions taking place between its ingredients  
82 during mixing. Kaddour et al. (2008) showed that during batter mixing chemical interactions  
83 take place between the ingredients and induce conformational changes in proteins and  
84 starch structures. These chemical changes can be assessed by spectroscopic investigations  
85 as FTIR spectroscopy, which is a particularly powerful tool for probing the secondary  
86 structures and conformations of protein/polysaccharides/lipid/water (Subramanian &  
87 Rodriguez-Saona, 2009; Sivam et al., 2012; Sivam et al., 2013). Moreover in combination  
88 with new methods of sample presentation such as Attenuated Total Reflectance (ATR) -  
89 which enables analysis of food matrix directly in the solid or liquid state without further  
90 preparation - FTIR allows the acquisition of high-quality spectra with high reproducibility from  
91 previously quite intractable materials (Wilson et al., 1988; Van de Voort et al., 1992). ATR-  
92 FTIR spectroscopy has been used to probe gluten secondary structure in dough under  
93 various conditions and formulations (Li et al., 2006; Wellner et al., 2005, Kaddour et al.,  
94 2008; Meziani et al., 2011; Sivam et al., 2012; Bock & Damodaran, 2013; Bock et al., 2013;  
95 Wang et al., 2014; Jazaeri et al., 2015). More recently, the poor quality of bran-enriched  
96 bread was explained by the conversion of  $\beta$ -turn structure into  $\beta$ -sheet and random  
97 structures when bran is added to the gluten or to wheat (Bock et al., 2013; Bock and  
98 Damodaran, 2013).

99 As regards starch, previous works have used this technique to estimate the amount of  
100 ordered or crystalline domains of starch or to study the starch gelatinization and  
101 retrogradation (Wilson et al., 1987; Wilson et al., 1988; Wilson & Belton, 1988; Van Soest et  
102 al., 1995; Flores-Morales et al., 2012; Ambigaipalan et al., 2014).

103 Despite the few studies carried out on ingredients functionalities in cakes systems  
104 (Wilderjans et al., 2008; Wilderjans et al., 2010), all of them were performed only on starch  
105 and gluten, neglecting the interactions between macromolecules that occur in the original  
106 batter. The aim of the present study was to investigate the role of ingredients interactions on  
107 cake batter directly by using ATR-FTIR spectroscopy. The present study explores the  
108 conformational changes in wheat proteins and starch in model batter systems prepared from  
109 batter ingredients (pregelatinized wheat starch, ~~pregelatinized maize starch~~, eggs, fat or/and  
110 sugar) to reach the final batter system.

111

## 112 **2. Materials and methods**

### 113 *2.1. Materials*

114 Wheat flour (protein: 11.6%, fat: 1.3%, starch: 83 %, ash: 0.5 % ~~ash~~; all on dry basis)  
115 was supplied by Giraudineau (France). Whole liquid eggs were purchased from Cargill  
116 kitchen solutions Inc., Monticello (MN, USA). Sugar was supplied by United Sugar  
117 Corporation (MN, USA). Fat consisted of rapeseed oil (70 %) and anhydrous milk fat (30 %)  
118 and was supplied by Corman (Belgium). ~~Sodium bicarbonate was supplied by ARM &~~  
119 ~~HAMMER, Princeton (New Jersey, USA).~~ Pregelatinized wheat starch (PWS) and  
120 ~~pregelatinized maize starch (PMS)~~ were supplied by Roquette (France).

121

### 122 *2.2. Model batter systems preparations*

123 The reference batter was a pound cake recipe (Hesso et al., 2014): 29.5% wheat  
124 flour, 25% sucrose, 25% whole liquid eggs, 20% fat and 0.5% sodium bicarbonate. 20% of  
125 flour was replaced by pregelatinized starch for the formula containing PWS.

126 Model systems were prepared by hand mixing for 5 min the ingredients (flour, PWS or  
127 PMS, eggs, sugar or/and fat) in the same proportion as present in reference batter, starting  
128 with the flour (S1) till reaching a complete and complex model with all ingredients in limited  
129 water content ranging from 23 to 39% (Table 1). The water content was chosen depending  
130 on the water content in the real batter (around 23%) as in the final model system (S6). For  
131 the flour systems (S1 and S2), the addition of water was essential for creating a homogenous  
132 mixture. While for flour + egg system (S3), the water was brought by adding liquid egg (77%  
133 water content). Freshly prepared batter was covered with a plastic paraffin film to prevent  
134 moisture loss. Each system was prepared in duplicate.

135 Moisture content (Table 1) of each sample was measured by drying the sample at  
136 130°C for 40 min by an infrared balance (MB 45, OHAUS, Parsippany, NJ, USA).

137

### 138 2.3. *ATR-FTIR spectroscopy*

139 ATR-FTIR spectroscopy was used to collect spectral data for protein secondary  
140 structures and starch crystalline and amorphous structures analysis. A Bruker Tensor 37  
141 (Bruker Optics, Inc., Billerica, MA, USA) was used with a horizontal multi-reflectance zinc  
142 selenide (ZnSe) crystal accessory. The instrument housed a deuterated tri-glycine sulfate  
143 (DTGS) detector. Spectra were collected in the 4000-600  $\text{cm}^{-1}$  infrared spectral range at  
144 room temperature. Each spectrum was an average of 32 scans at 4  $\text{cm}^{-1}$  resolution. A  
145 background spectrum of the empty trough sampling plate was collected before each sample.  
146 Spectra were collected within 3 minutes after batter preparation and a minimum of 4 spectra  
147 for each sample was used for spectral analysis. The sample was pressed firmly onto the  
148 crystal to eliminate air and to achieve better contact. Spectral analysis was performed as  
149 described by Bock et al. (2013) using OPUS software v. 7.0. Reference  $\text{H}_2\text{O}$  –  $\text{D}_2\text{O}$  spectra  
150 (at 25, 30, and 37% water content) were collected and used to correct the sample moisture  
151 content for protein analysis. All spectra were vector-normalized to correct any differences in  
152 sample penetration depth. Vector-normalized spectra were subsequently offset corrected  
153 before digital subtraction of  $\text{H}_2\text{O}$  –  $\text{D}_2\text{O}$  reference spectra representing the same moisture



154 content. For ingredients spectra, air compensation, base line correction and smoothing were  
155 done before normalization.

156

### 157 2.3.1. *Protein secondary structure estimation*

158 The quantitative estimation of proteins secondary structure in different model systems  
159 was determined from second-derivative spectra of a 5-point Savitsky-Golay function  
160 according to Bock et al. (2013), in order to facilitate white-noise removal and resolve the  
161 individual band component corresponding to specific secondary structure (Kong and Yu,  
162 2007). The difference spectra resulting from digital subtraction were second derivated before  
163 the analysis of the amide I band ( $1600 - 1700 \text{ cm}^{-1}$ ). The characteristic mean absorption  
164 frequencies of the secondary structural elements in proteins are listed in Table 2. The  
165 secondary structure estimate was determined from the relative area of the peaks centered at  
166 these absorption bands (Bock et al., 2013). Each structure was expressed as percentages of  
167 the proteins total secondary structures.

168

### 169 2.3.2. *Starch crystalline and amorphous structures*

170 To study the effect of the ingredients interactions on the starch amorphous and  
171 crystalline structures, the region  $800-1200 \text{ cm}^{-1}$  of normalized spectra was used. The amount  
172 of short-range ordering of the starch samples can be expressed by the intensity ratio of the  
173 bands most characteristic of crystalline at  $1047 \text{ cm}^{-1}$  and amorphous at  $1022 \text{ cm}^{-1}$  starch R  
174 ( $1047/1022$ ) or by using the intensity ratio of the band characteristic of crystalline starch at  
175  $1047$  and  $1035 \text{ cm}^{-1}$  R' ( $1047/1035$ ) (Van Soest et al., 1995), where  $1035$  is the valley  
176 between the two bands ( $1047$  and  $1022 \text{ cm}^{-1}$ ). These two ratios could explain the crystallinity  
177 in two ways: R ( $1047/1022$ ) explains the changes due to the modifications in starch  
178 crystalline structure and amorphous form, while R'( $1047/1035$ ) explains the changes related  
179 just to crystalline structure.

180

### 181 2.4. *Statistical analysis*

182 Each model system was prepared in duplicate, and at least 4 replicates were carried  
183 out for each sample, so that at least eight replicates were performed for each model system.  
184 Differences amongst model systems were assessed at the 5% level, using analysis of  
185 variance (ANOVA), which was performed by using Microsoft Excel (V. 2013).

186

### 187 **3. Results and Discussion**

#### 188 *3.1. ATR-FTIR spectra for batter ingredients*

189 Fig.1 shows the ATR-FTIR spectra of all the ingredients. Flour, PWS, ~~PMS~~ and sugar  
190 were analyzed in the dry state. The spectra of the ingredients were similar to those reported  
191 in previous works (Wilson et al, 1988; Meziani et al., 2011; Sivam et al., 2012 and 2013). The  
192 band in the OH stretch region ( $3000\text{-}3700\text{ cm}^{-1}$ ) for flour, pregelatinized starches and egg  
193 spectra is mostly related to water (Sivam et al., 2013). Wheat flour showed a broad bimodal  
194 peak band centered at  $3410\text{ cm}^{-1}$  and  $3242\text{ cm}^{-1}$ . The former is attributed to small hydrogen  
195 bonded clusters, the latter to extensively hydrogen-bonded water and associated chains of  
196 water (Jain et al., 1989; Sutandar et al., 1994). The bimodal distribution could be explained by  
197 the possibility that not all the water is tightly associated with flour components (Bock et al.,  
198 2013). While PWS and ~~PMS~~ showed only one peak related to the OH stretch at  $3325\text{ cm}^{-1}$   
199 suggesting that the majority of water could be associated to starch (Bock et al., 2013). The  
200 broad peak in the OH stretch region in eggs is related to the high moisture content of this  
201 sample (77%). The absorption band in both flour and eggs at  $1600\text{-}1700\text{ cm}^{-1}$  is attributed to  
202 amide I (80% C=O stretch and 10% N-H bending), which is the most sensitive spectral region  
203 to the protein secondary structural components (Sivam et al., 2013). The peaks at  $800\text{-}1200$   
204  $\text{cm}^{-1}$  in flour and PWS and ~~PMS~~ spectra are characteristic for starch crystalline and  
205 amorphous structures and showed bands at  $1077$ ,  $1047$ ,  $1022$ ,  $994$ , and  $928\text{ cm}^{-1}$  (COH  
206 bending and  $\text{CH}_2$  related modes) (Wilson et al., 1988; Van Soest et al., 1995). Flour spectra  
207 exhibited an intense absorption signal at  $1019\text{ cm}^{-1}$  – which is characteristics of starch - and  
208 weaker features at  $1529$  (amide II) and  $1640$  (amide I)  $\text{cm}^{-1}$  - characteristic bands of gluten –  
209 in agreement with relative proportions of starch (62–72%) and gluten (6–13%) in wheat flour.

210 Eggs showed also a weak absorption intensity in the 3000-2800  $\text{cm}^{-1}$  region that  
211 corresponds to lipids, which is more intense in fat spectra. Fat spectra exhibited high  
212 absorption intensities at 3013  $\text{cm}^{-1}$ , 2937  $\text{cm}^{-1}$ , and 2856  $\text{cm}^{-1}$ , which are associated with the  
213 asymmetric stretch of  $\text{CH}_3$ , the asymmetric stretch of  $\text{CH}_2$ , and the symmetric stretch of  $\text{CH}_2$   
214 of aliphatic fatty acid chains, respectively. It showed an intensive absorption at 1743  $\text{cm}^{-1}$   
215 attributed to C=O ester groups and peaks at 1240  $\text{cm}^{-1}$  and 1195-1129  $\text{cm}^{-1}$  are related to C-  
216 O stretching (Yang et al., 2005).

217 Finally, sugar showed intense and characteristic bands in the region between 1200  
218 and 900  $\text{cm}^{-1}$  and bands between 2800 and 3700  $\text{cm}^{-1}$ . The first bands are assigned to  
219 deformation of  $-\text{CH}_2$  and angular deformation of C-C-H and H-C-O, while the others are  
220 related to water (Bureau et al., 2009).

221 In this study, attention has been paid on the amide I region (1600-1700  $\text{cm}^{-1}$ ) and  
222 starch region (800-1200  $\text{cm}^{-1}$ ) in order to investigate the impact of ingredients addition on  
223 gluten secondary structure and starch conformation in cake batter.

224

## 225 3.2. ATR-FTIR spectra for model batter systems

### 226 3.2.1. Effect of ingredients interactions on protein conformational structure

227 The ATR-FTIR absorbance spectra for the batter model systems prepared with flour  
228 (S1) and pregelatinized starch (S2) are shown in Fig. 2a. As expected, the intensity of the  
229 OH stretch band (3000-3700  $\text{cm}^{-1}$ ) increased when water was added to flour and flour + PWS  
230 systems. In addition, the intensity of the absorption band in the amide I region (1600-1700  
231  $\text{cm}^{-1}$ ) increased, suggesting changes in protein secondary structure. The relative amount of  
232 secondary structures in wheat flour (in dry state) followed the order  $\beta$ -sheet (59.9%) >  
233 random (31%) >  $\beta$ -turn (7.8%) >  $\alpha$ -helix (1.3%) (Fig. 2b). Water addition to flour (S1) - together  
234 with mixing step - changed this order. The secondary structure contents of protein estimated  
235 for S1 followed the order  $\beta$ -sheet (48.7%) > random (26%) >  $\alpha$ -helix (15.7) >  $\beta$ -turn (9.6%) (Fig.  
236 2b) indicating that water addition rearranged the protein molecules but kept the  $\beta$ -sheet  
237 structure as the preferred secondary structure of wheat flour, in agreement with previous

238 studies carried out on wheat flour at various hydration states (35-50% moisture content)  
239 (Bock et al., 2013). However, after water addition and mixing, the structure changed from an  
240 ordered structure ( $\beta$ -sheets) to an unordered structure ( $\alpha$ -helix). The low percentage of  $\beta$ -  
241 turns in system 1 is consistent with the fact that the development of a gluten network is  
242 limited in batters (Huebner et al., 1999). The effect of gluten development on  $\beta$ -turns  
243 structures has been well documented in previous studies (Bock & Damodaran, 2013): the  $\beta$ -  
244 turn increase at the expense of the  $\beta$ -sheet and the random structures as the water content  
245 increased.

246 The effect of pregelatinized starch on protein secondary structure is shown in Fig. 2b.  
247 The positive effect of pregelatinized starches on cakes texture has been proved (Sozer et al.,  
248 2011, Hesso et al., 2014), while this is the first attempt to investigate their effect on the  
249 protein structure. In this study, pregelatinized wheat starch (PWS) was tested in batter model  
250 systems. No significant difference of their impact on protein secondary structure was found.  
251 Consequently, only the results of PWS will be presented and discussed. System 2 (Fig. 2)  
252 was prepared by the partial substitution of the flour with PWS at the same moisture content  
253 as S1 (35%). The protein secondary structure estimated for the S2 followed the same order  
254 as the S1:  $\beta$ -sheet (53.2%) > random (23.8%) >  $\alpha$ -helix (14.5%) >  $\beta$ -turn (8.6%), with a slight  
255 but significant ( $P < 0.05$ ) increase in  $\beta$ -sheets structure at the expense of unordered  
256 structures (Fig. 2b). This change could be related to the competition between the PWS and  
257 wheat flour protein for water, as described by Bock et al. (2013) for bran. Components able  
258 to absorb water - such as pregelatinized starches, hydrocolloid or fiber - affect the water  
259 distribution among dough components promoting a partial dehydration of gluten and the  
260 collapse of  $\beta$ -spirals (consecutive  $\beta$ -turns) into  $\beta$ -sheet structures (Sivam et al., 2012; Bock et  
261 al., 2013).

262 The effect of eggs, fat, sugar and their combination on protein conformation is shown  
263 in Fig. 3. Eggs addition to flour (S3) increased  $\beta$ -sheet structure from 48.7% to 56% at the  
264 expense of unordered structure which decreased from 26% to 17%. These changes reflect  
265 the protein secondary structure in liquid egg: 74.1%  $\beta$ -sheet, 13.8%  $\alpha$ -helix, 9% random and

266 3.1%  $\beta$ -turns. According to Bruun (2006), the  $\beta$ -sheet structure is the most important  
267 structure for protein-protein interaction. Therefore, it is possible that  $\beta$ -sheets structures built  
268 up in the network between flour protein and egg proteins when the flour was mixed with other  
269 batter components such as eggs due to eggs proteins-gluten interaction.

270 The addition of the fat to flour in system 4 (S4) promoted the formation of  $\alpha$ -helical  
271 structures- which increased from 16% to 35% - and the decrease in  $\beta$ -sheet structure (from  
272 49% to 22%) confirming previous findings on a bread system (Sivam et al., 2012). The  
273 change in conformation in presence of lipids could be related to the decrease of the  
274 interactions among hydrophilic molecules; it has been hypothesized that in presence of oil,  
275 water molecules move less freely and that, consequently, the gluten-water interaction is  
276 limited/restricted (Sivam et al., 2012). They showed that the presence of the oil in bread  
277 dough formulation decreased the  $\beta$ -sheet structure, promoting fewer intermolecular hydrogen  
278 bondings.

279 Adding sugar to flour (system S5) increased the  $\beta$ -sheet from 48.7% to 55% and  
280 decreased the  $\alpha$ -helix structure from 15.7% to 10 % (Fig. 3). Sugar competes with flour  
281 proteins for water and also may attach to the hydrophobic pockets of gluten side chains,  
282 which led to more intermolecular hydrogen bondings promoting more  $\beta$ -sheets (Sivam et al.,  
283 2012). Sivam et al. (2012) showed that the sugar addition to a bread formulation led to a  
284 decrease in  $\alpha$ -helices (at  $1653\text{ cm}^{-1}$ ) in amide I band. The sugar seems to act contrary to the  
285 fat concerning the intermolecular hydrogen bonds.

286 Protein conformation of batter model system (S6) - which includes all the ingredients -  
287 was characterized by 22.5%  $\beta$ -sheet, 41%  $\alpha$ -helix, 33.5% random and 3%  $\beta$ -turns. A general  
288 look at the protein conformational changes resulted from each ingredient addition (Fig.3),  
289 showed that fat addition (S4) promoted the most important conformational change in the final  
290 batter system. These results confirmed that the fat is the functional ingredient in the cake  
291 batter, and as in S4, it decreased the intermolecular  $\beta$ -sheets between gluten and egg  
292 protein which un-stabilized and decreased the hydrogen bonding of  $\beta$ -turns (Sivam et al.,  
293 2012). Meziani et al (2011) demonstrated that the  $\beta$ -sheets structure is the preferred

294 secondary structure of gluten in sweet doughs. In the present study, the  $\beta$ -sheets were the  
295 dominant structure of flour model systems (S1, S3 and S5). This was not the case for the  
296 systems containing fat (final batter system and S4) where  $\alpha$ -helix structure dominated. These  
297 conformational changes in proteins structure between the flour system (S1) and the final  
298 batter system (S6) could explain the importance of fat in the batter ingredients interactions  
299 which led to a weak gluten development which was already affected by water content and  
300 sugar presence. Changes in protein conformation in system S6 due to fat addition could be  
301 explained by two mechanisms, and taking into consideration that in S6 proteins from wheat  
302 and egg contribute to the final network. As regards flour proteins, the presence of fat reduced  
303 water mobility limiting protein accessibility to water (Sivam et al., 2012). While egg proteins  
304 could be adsorbed on the surface of fat - as in emulsions (Graham and Phillips, 1979) -  
305 stabilizing the emulsion in the batter system and improving its structure homogeneity, and  
306 likely affecting the cake functionality.

307 The PWS was studied in the different systems with batter ingredients. The presence of PWS  
308 did not affect dramatically the protein conformation (data not shown) with a slight but  
309 significant ( $P < 0.05$ ) increase in  $\beta$ -sheets compared to the flour alone.

310

### 311 *3.2.2. Effect of ingredient interactions on starch amorphous and crystalline structures*

312 As mentioned above, batter properties could be affected not only by protein but also  
313 by starch (Bruun, 2006). This consideration led us to the second objective of this study which  
314 concerns the effects of batter ingredients on starch conformational changes in the crystalline  
315 and amorphous structures. The FTIR spectra of flour (S1) and Flour + PWS (S2) reported in  
316 Fig. 2a showed a broad envelope at 1200– 800  $\text{cm}^{-1}$  with bands at 1047, 1022 and 994  $\text{cm}^{-1}$   
317 - related to crystallinity and to vibrational modes within the amorphous domains of starch  
318 granules (Van Soest et al., 1995). These bands were previously identified in wheat, potato,  
319 maize, waxy maize and amylo maize starches (Wilson et al., 1988). The intensity ratios R  
320 (1047/ 1022) and R'(1047/ 1035) were used to express the amount of ordered crystalline  
321 domains with respect to amorphous domains in native starch gels (Wilson et al., 1987 et

1988, Van Soest 1995), starch granules (Sevenou et al., 2002), doughs (Meziani et al., 2011; Sivam et al., 2013), bread (Sivam et al., 2013), and tortillas (Flores-Morales et al., 2012). However, since the penetration depth of the IR beam in the ATR-FTIR system is about 2  $\mu\text{m}$ , the organization investigated by ATR-FTIR is limited to the regions near the granule surface (Ambigaipalan et al., 2014). The ATR-FTIR spectra of starch structures related regions for flour, PWS and flour + PWS are shown in Fig. 4. The ratio  $R'$  (1047/1035) was  $0.90 \pm 0.01$ ,  $0.88 \pm 0.01$  and  $0.83 \pm 0.01$  for flour, flour + PWS and PWS respectively, while no significant changes were observed for  $R$ , suggesting a general increase in the spectra intensity with the PWS. The ratio  $R$  (1045/1022) for native wheat starch (0.63) given by Sevenou et al. (2002) was in agreement with these results. The decrease in crystalline ratio  $R'$  with the addition of pregelatinized starch was caused by the increase in starch amorphous structure when the PWS was added, which can be clearly observed in the PWS specter alone (Fig. 4). Investigating the starch gelatinization and retrogradation, Wilson et al. (1988) found that the bands at  $1046 \text{ cm}^{-1}$  and  $1000 \text{ cm}^{-1}$  – which represent the starch crystalline structure - were disappeared during gelatinization but gradually reformed during storage. It is consistent with the fact that the gelatinized starch gave more disordered structure and less crystalline structure as in the case of the PWS used in batter systems. ~~Since the effects of both PWS and PMS on starch conformational changes were quite similar (data not shown), only the role of PWS in batter system was presented and discussed.~~ Fig.4 showed a shift of the crystalline peak towards higher frequency for the PWS alone. This should be related to the establishment of hydrogen bonds between neighboring helices during growth of the crystal structure, in another word the complex amylose-lipids which is already formed in the PWS (Rappenecker & Zugenmaier, 1981).

When water was added to flour and flour + PWS mixtures (S1 and S2), the normalized absorbance at  $1047$  and  $1022 \text{ cm}^{-1}$  were smaller than in the dry state (Fig. 5), possibly suggesting a more ordered saccharide conformation with fewer conformations which give smaller distribution of bond energies in dry state. Sivam et al. (2013) found that interestingly the  $1100\text{--}900 \text{ cm}^{-1}$  envelope was weaker as the water content in bread dough

350 increased. Van Velzen et al. (2003) explained that an increase in available water thus may  
351 have changed the bonding arrangement and diluted the signal. On the other hand, no  
352 changes in the ratios were detected after adding water to the flour (S1) compared to flour  
353 (dry state) (Table 3). The decrease in crystallinity ratio  $R'$  and even in  $R$  by the PWS in  
354 system 2 (Table 3) could be due to the interaction between water and the PWS promoting  
355 more amorphous structure. This was confirmed by analyzing the pregelatinized wheat starch  
356 with the same water content as in systems S1 and S2 (data not shown).

357 Starch region ATR-FTIR spectra and intensity ratios for flour with batter ingredients  
358 addition (egg, fat or/and sugar) are shown in Fig.6. Both ratios  $R$  and  $R'$  increased when the  
359 egg was added to flour (S3). This indicates an increase in the intensity of the band at  $1046$   
360  $\text{cm}^{-1}$  and a decrease in the intensity of the band at  $1022 \text{ cm}^{-1}$ . The valley formed between the  
361 two bands is growing and therefore its intensity decreases. The changes in the intensity of  
362 these bands by egg addition reflected an increase in crystallinity ratio that could probably be  
363 explained by the water availability in the matrix as water provided into the system by the egg  
364 will be more easily available for egg proteins than for starch. Fat addition to flour (S4)  
365 increased the ratios, due to similar changes in the intensity of the bands as described for  
366 eggs addition. The changes with fat addition could be explained by slowing down the  
367 hydration of starch by its hydrophobic effect (Wilderjans et al., 2013). Bogracheva et al.  
368 (2001) studied the effect of water content on the ordered/disordered structures in starches.  
369 They concluded that the proportion of the ordered structure depended on the water content.  
370 With low water content, the proportion of the ordered structures was significantly reduced.  
371 This means that the presence of any batter ingredients would prevent the access of water to  
372 starch granules affecting its crystalline and ordered structures, as the intensity ratios  
373 changed by fat or/and egg addition (Fig. 6). The same tendency was found with sugar  
374 addition to flour in system 5 with more important increase in  $R$  as in S3 or S4. One of the  
375 reasons of the crystalline increase could be the competition for water between sugar and  
376 starch ~~as in the case of egg addition~~. On the other hand, sugar has a crystalline peak (Fig. 1)  
377 which could interfere with starch structures and results in the important increase in crystalline



378 intensity values (Bureau et al., 2009). Even in a solution, the sugar showed an absorbance at  
379 the bands characteristic to starch (results not shown).

380 When all ingredients were added (egg, fat and sugar), an increase in crystalline to  
381 amorphous ratios was observed (Fig. 6: S6) compared to flour model system (S1). The  
382 model batter system (S6) crystalline ratio R was in agreement with previous work on a sweet  
383 dough by Meziani et al. (2011), with the R (1047/1022) value of  $0.898 \pm 0.016$ . These  
384 conformational changes in the amorphous and crystalline structure were due to a combined  
385 effect of all ingredients which defined the final batter structure. This increase should be  
386 related to the interaction between ingredient and the availability of water for starch (Hedley et  
387 al., 2001). Van Soest et al. (1995) showed an increase in R' with the increase in water  
388 content for potato starch. They showed that the short-range order in starch is sensitive to  
389 changes in water content.

390 The effect of the PWS was studied on starch structures for all model systems (Table  
391 4). In general, the PWS slightly decreased the crystalline ratio for the S3, S4 and S5 with the  
392 PWS addition, which confirmed the previous results on flour alone (S2). The flour + PWS  
393 mixtures had more amorphous structure than the flour mixtures (S1, S3 and S5). However,  
394 this was not found in the final batter systems (S6 + PWS), where the starch structure ratios  
395 were similar to the S6 (without PWS presence) as shown in Table 4. This could be due to the  
396 combined effect of all ingredients (fat, sugar and egg) which was more pronounced than the  
397 effect of PWS addition. PWS addition should be considered as a positive point, since the  
398 cake with PWS will have the same ratio of starch amorphous and crystalline structures - or  
399 decreased crystalline structure as found in some studied model systems (S2 or S3+PWS).  
400 The pregelatinized starch used in this study did not show a crystalline structure likely due to  
401 the retrogradation of amylose and/or amylopectin (data not shown). Therefore, adding PWS  
402 in cake formulation would not affect the batter crystallinity and would not promote a fast  
403 staling after baking compared to the reference cake (Hesso et al. 2014).

404

#### 405 **4. Conclusions**

406           The present study investigated the effect of ingredients on the proteins secondary  
407 structures and starch conformational structure taking place during batter preparation by ATR-  
408 FTIR. The PWS addition to the batter did not dramatically affect the protein secondary  
409 structures or the starch crystallinity. This positive result highlights the possibility of using  
410 pregelatinized starches in cake formulation to inhibit the staling phenomenon without  
411 affecting the protein secondary structure and likely the quality of the final product.  $\alpha$ -helix  
412 structure is the predominant protein conformational structure in flour + fat system and cake  
413 batter, while the  $\beta$ -sheet structures are predominant in flour and dough systems from the  
414 literature. These results highlighted the limited development in gluten network in cake batter,  
415 since  $\beta$ -turn structures are predominant in well-developed gluten network. Moreover, fat has  
416 a key role in cake batter and its functionality is likely the most important in batter. The need  
417 to produce cakes with low fat content leads to the research for a fat-replacer which is able to  
418 keep the  $\alpha$ -helix structure as the main protein structure in the final product.

419

#### 420 **Acknowledgements**

421 This work has been funded by the regional University LUNAM (international cooperation), by  
422 GEPEA-ONIRIS, Nantes, France and the University of Minnesota, Saint Paul, USA.

423

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536

Table 1.

	Flour (g)	PWS (g)	Egg (g)	Fat (g)	Sugar (g)	Moisture content (%)
S1: Flour	100	-	-	-	-	35
S2: Flour + PWS	80	20	-	-	-	35
S3: Flour + egg	100	-	85	-	-	39
S4: Flour + fat	100	-	-	67	-	29
S5: Flour + sugar	100	-	-	-	85	29
S6: Flour + egg + fat + sugar	100	-	85	67	85	23

Table 2.

Mean frequencies ( $\text{cm}^{-1}$ )	Secondary structure assignment
1620-1641	$\beta$ -sheets
1643-1651	unordered (random)
1653-1659	$\alpha$ -helix
1660-1684	$\beta$ -turns



Table 3.

	R' (1047/1035)	R (1047/1022)
Flour (dry state)	0.90±0.01 <sup>c</sup>	0.70±0.01 <sup>b</sup>
Flour + PWS (dry state)	0.88±0.01 <sup>b</sup>	0.70±0.01 <sup>b</sup>
PWS (dry state)	0.83±0.01 <sup>a</sup>	0.69±0.01 <sup>b</sup>
S1: Flour	0.91±0.02 <sup>c</sup>	0.69±0.06 <sup>b</sup>
S2: Flour + PWS	0.84±0.02 <sup>a</sup>	0.64±0.04 <sup>a</sup>

Table 4.

	R' (1047/1035)	R (1047/1022)
S1: Flour	0.91±0.02 <sup>b</sup>	0.69±0.06 <sup>a</sup>
S2: Flour + PWS	0.84±0.02 <sup>a</sup>	0.64±0.04 <sup>a</sup>
S3: Flour + egg	0.98±0.01 <sup>c</sup>	0.85±0.01 <sup>b</sup>
S3 + PWS	0.92±0.01 <sup>b</sup>	0.82±0.03 <sup>b</sup>
S6: Flour + egg + fat + sugar	1.10±0.01 <sup>d</sup>	1.17±0.02 <sup>c</sup>
S6 + PWS	1.11±0.01 <sup>d</sup>	1.17±0.02 <sup>c</sup>

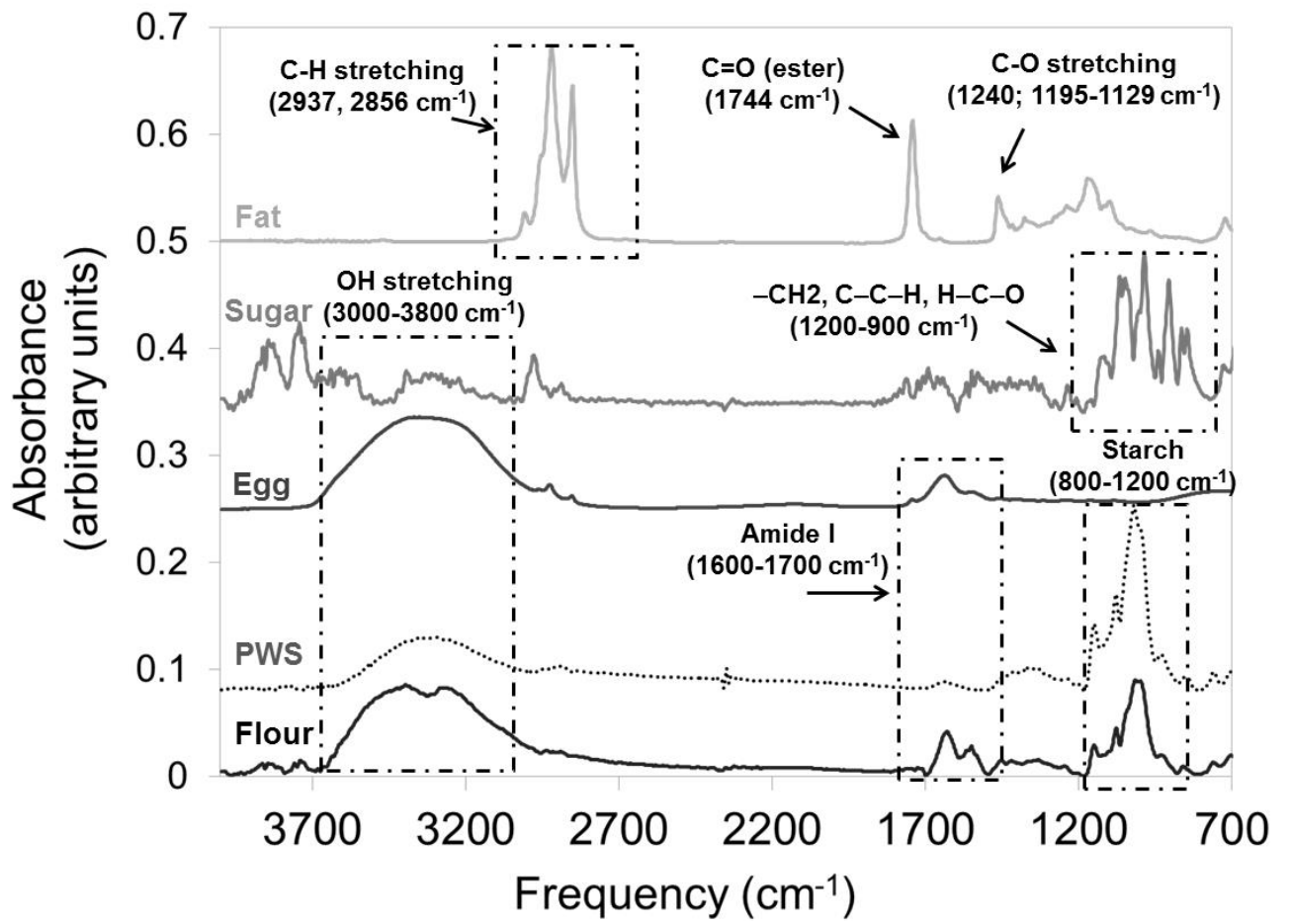
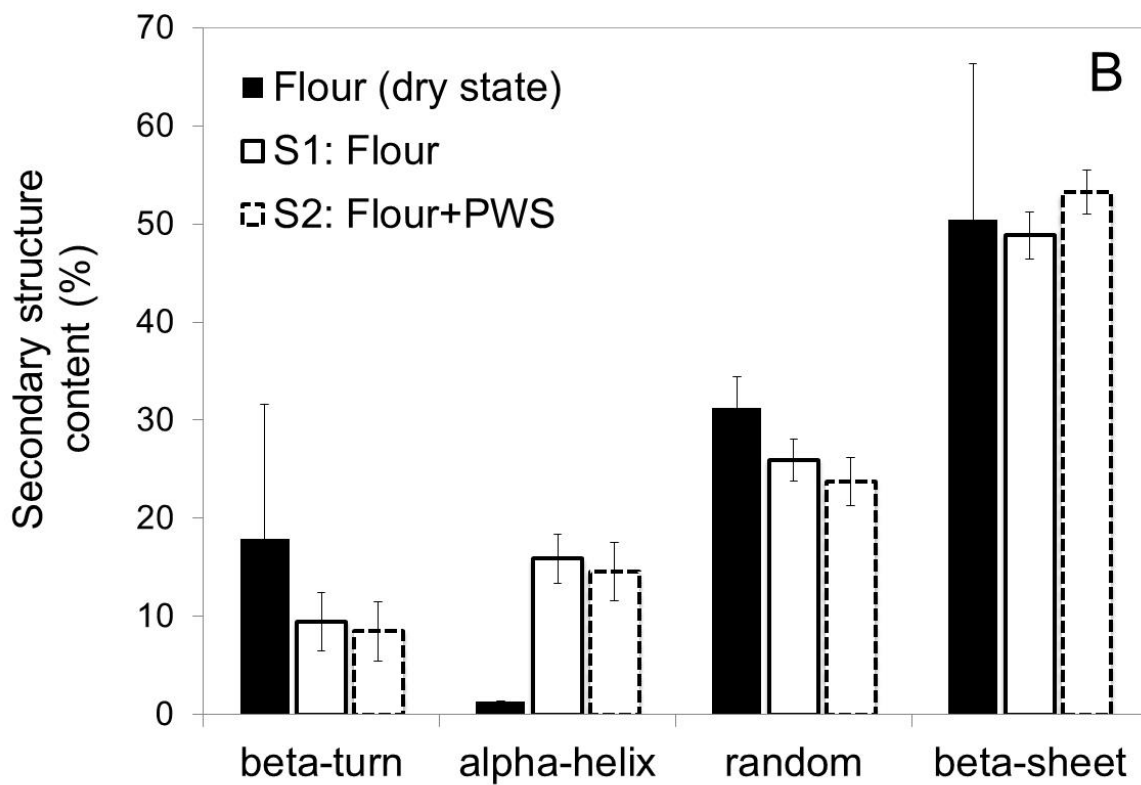
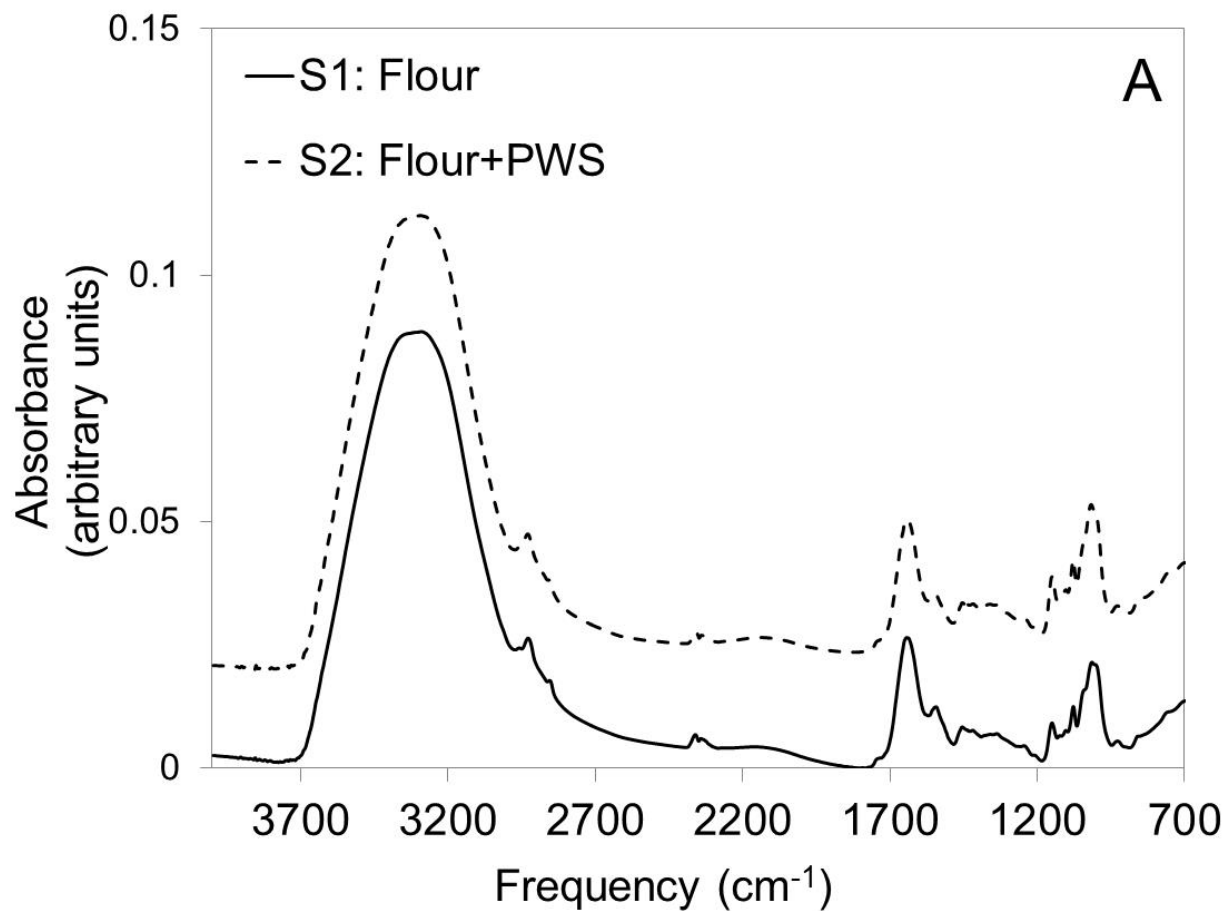


Fig. 1



**Fig. 2**

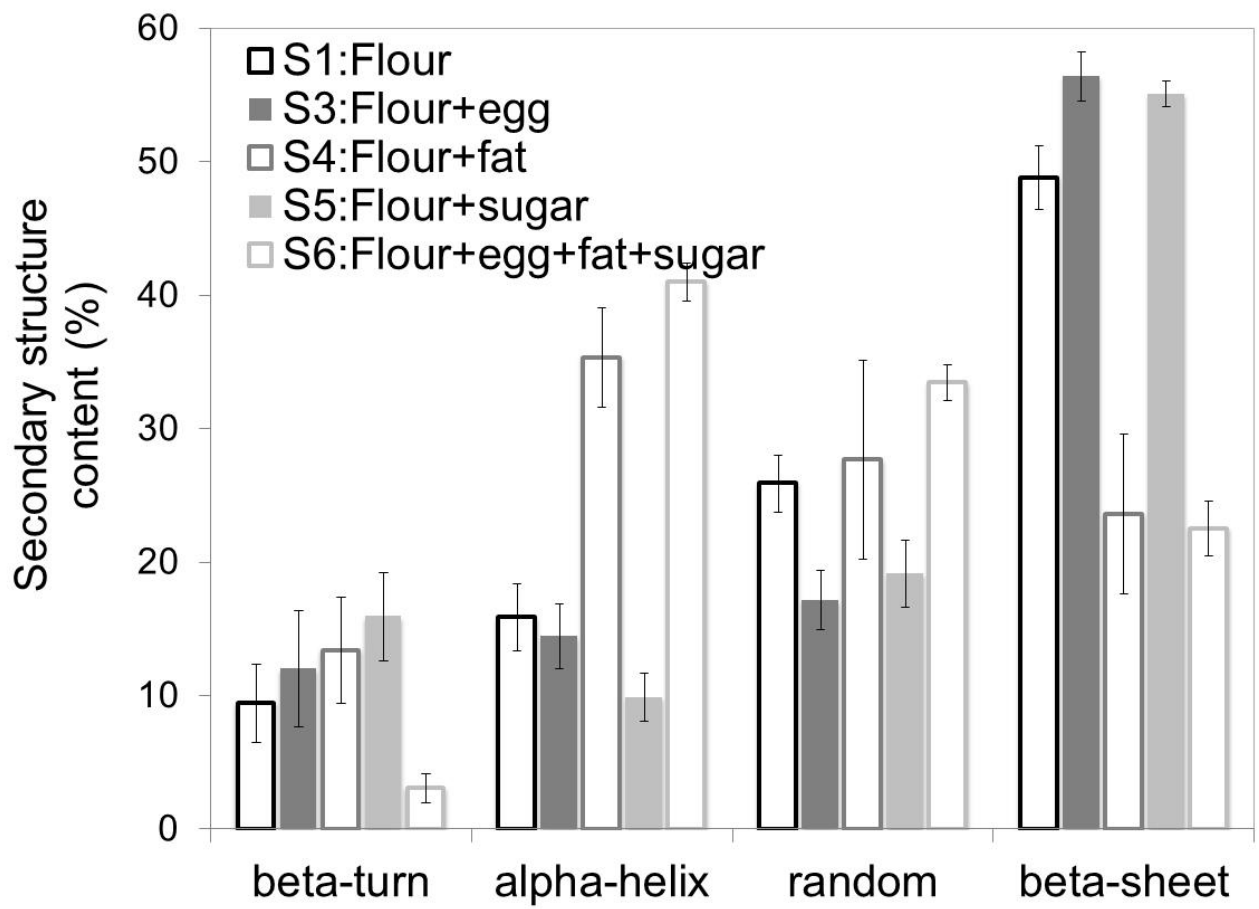


Fig. 3

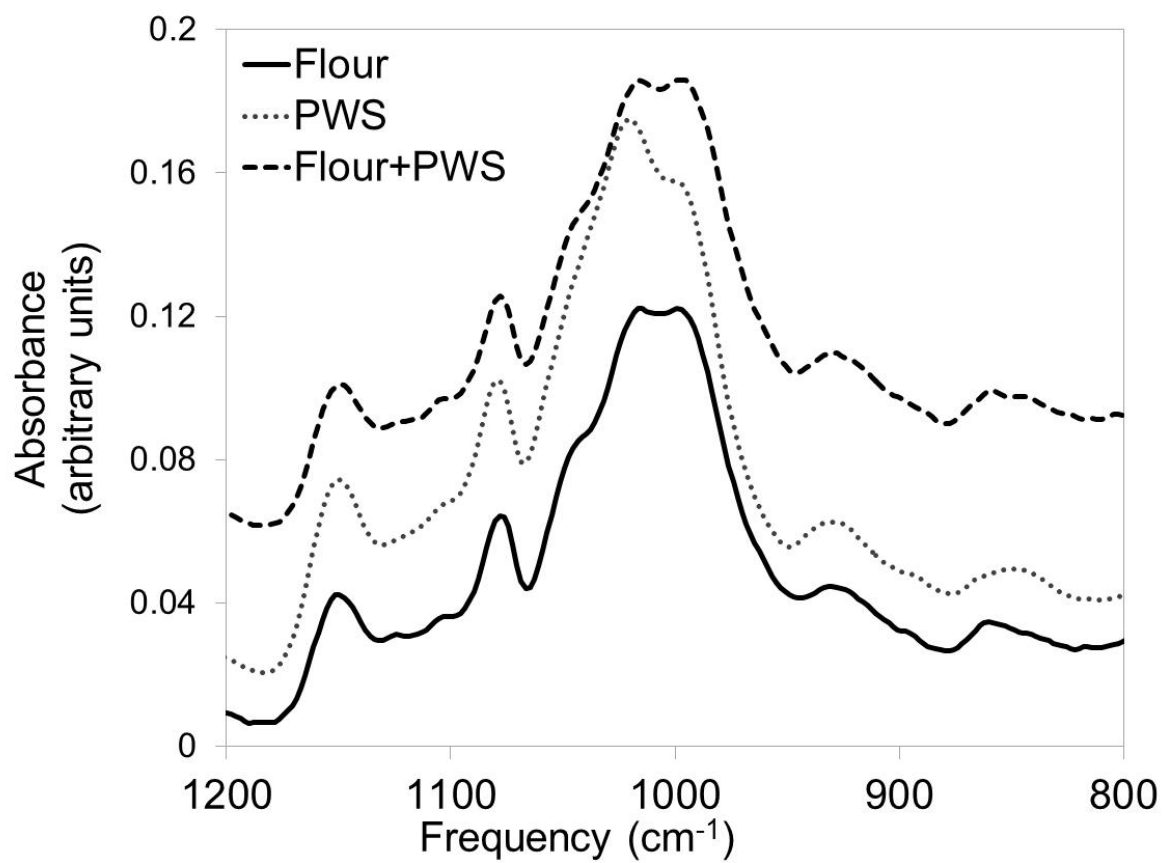


Fig. 4

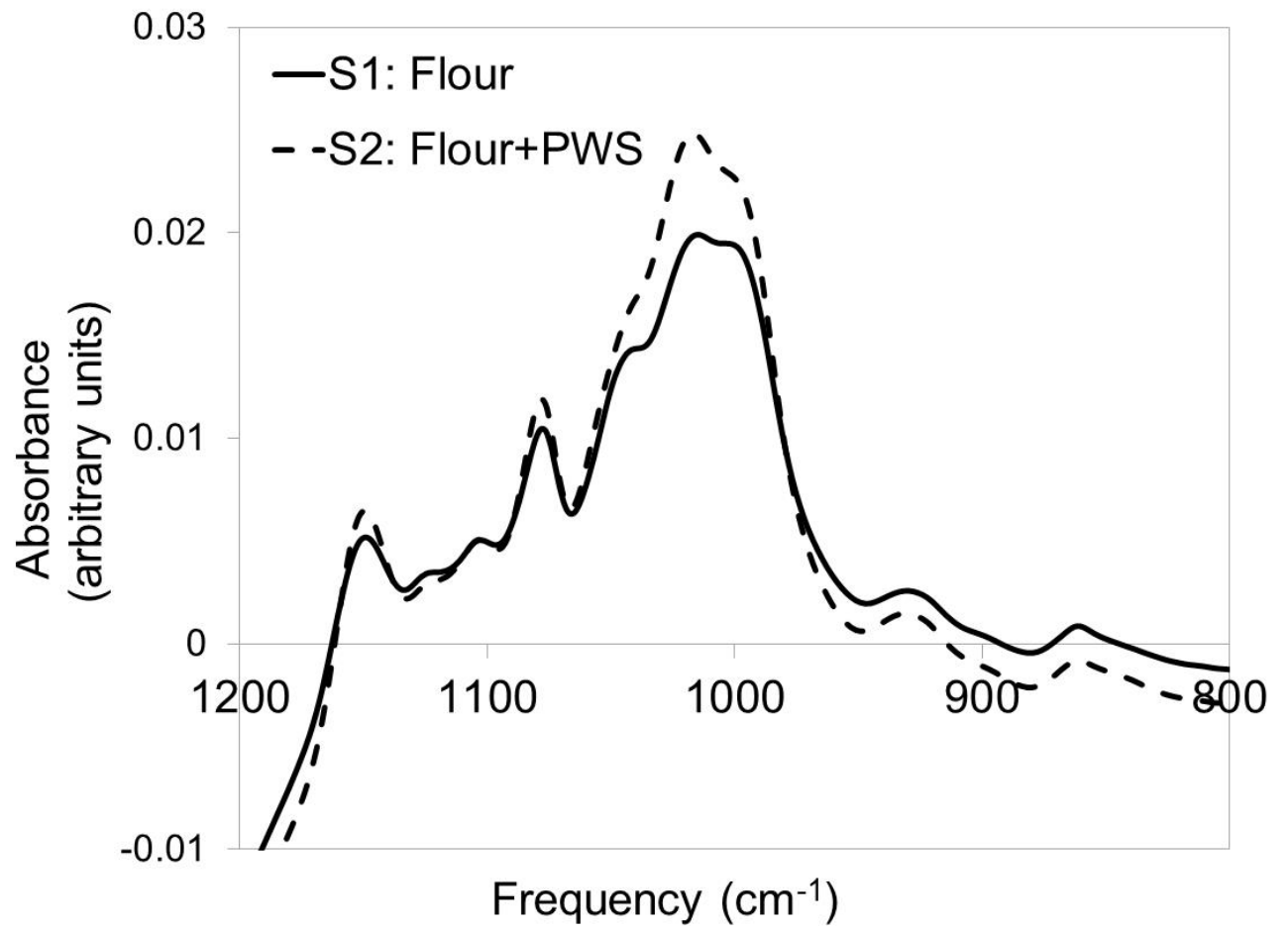


Fig. 5

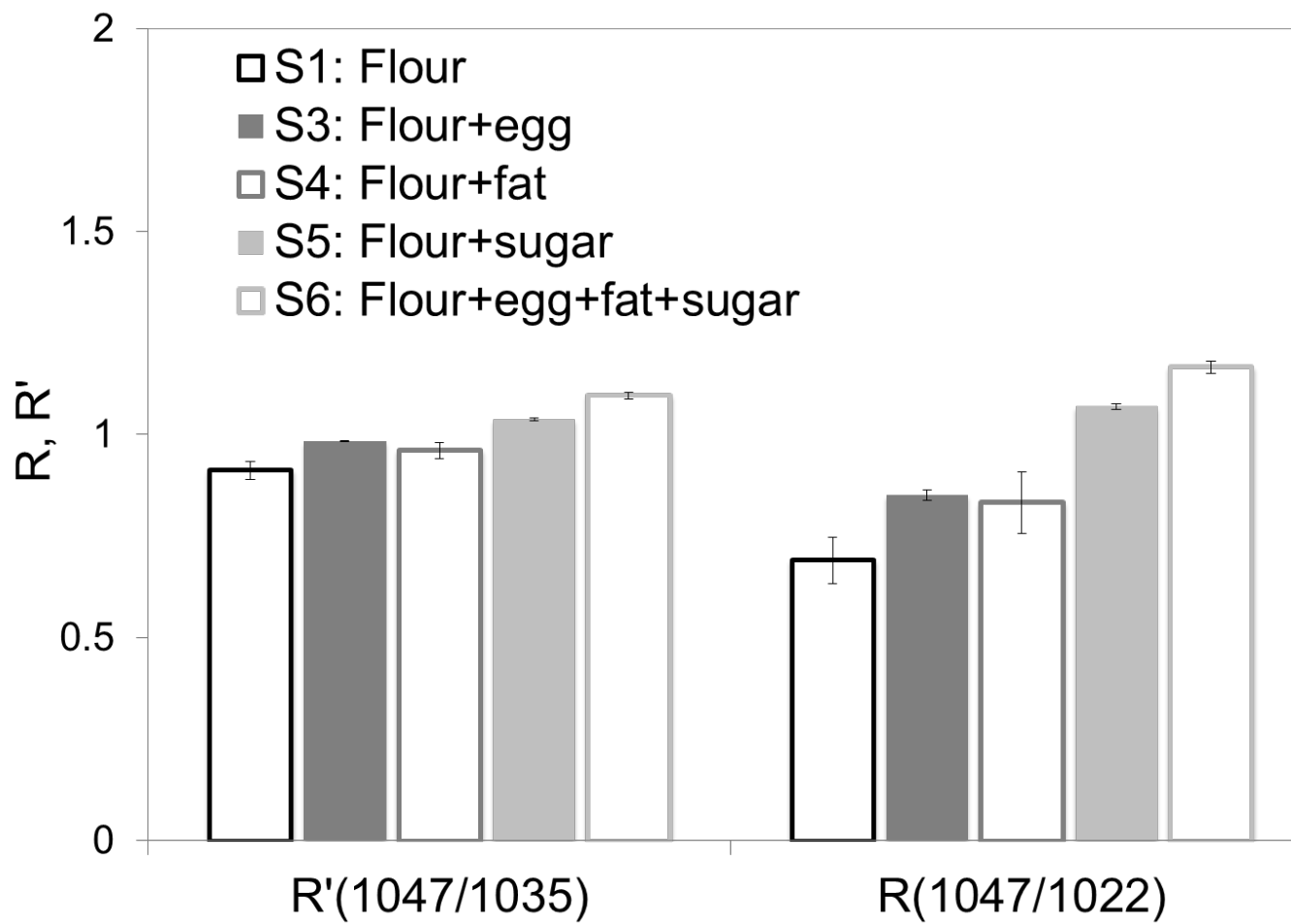


Fig. 6