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## **Bread wheat quality under limiting environmental conditions:**

### **II - Rheological properties of Lebanese wheat genotypes**

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**1 ABSTRACT**

2 In the general framework of a program to improve the local production of common wheat by  
3 the Lebanese State, we have characterized the rheology of different bread wheat cultivars  
4 selected for their adaptation to semi-arid weather conditions. After a biochemical  
5 characterization [i.e. synthesis and accumulation of the major constituents of the grains  
6 (mainly storage proteins and starch)] of the plant material selected in a previous work, the  
7 main technological behavior of the flour that resulted from these grains and associated with  
8 bread-making properties was evaluated in the present study. Despite the selection of the plant  
9 material used in this study, the results demonstrate that environmental conditions inducing  
10 limitations in reserve accumulation [i.e. high gliadin content, very high level of  
11 polymerization/aggregation of polymeric prolamins, significant increase in the  
12 amylopectin/amylose ratio, modifications in the distribution of starch granules (A-type vs. B-  
13 type)] during grain filling affected the rheological behavior. The studied flours showed high  
14 wet and dry gluten contents, high Zeleny values, and a low gluten index value. They also  
15 showed high extensibility on the alveograph and extensograph and elevated dough strength on  
16 the farinograph, as well as great water absorption. Furthermore, flours of the studied cultivars  
17 did not express their optimal rheological potential in spite of their favorable glutenin subunit  
18 composition.

19

20 **Keywords:**

21

22 Bread wheat; Semi-arid environments; Technological quality; Rheological behavior; Limiting  
23 weather conditions; Bread making properties.

24

## 25 1. Introduction

26 As presented in a previous publication (Sakr et al. 2020), for several years, the Lebanese  
27 state has supported the introduction of local varieties of common wheat in order to limit the  
28 volume of its imports. In this context, a general improvement program has been put in place  
29 to select plant material adapted to environmental conditions (i.e., good productivity under  
30 semi-arid conditions) that can lead to national production of a high-quality product [i.e.,  
31 respecting the needs expressed by Lebanese processors (i.e., millers and bakers)]. To this end,  
32 a specific panel of local varieties of common wheat was selected by the Grain and Vegetable  
33 Research Department of Lebanese Agricultural Research Institute Grain (LARI) with  
34 ICARDA and ACSAD, because of their agronomic behavior in the face of environmental  
35 constraints.

36 Within the general framework of a characterization of the plant material selected, an  
37 earlier study (Sakr et al. 2020) focused specifically on the synthesis and accumulation of the  
38 major constituents of the grains harvested at the end of different cropping years (i.e., 2016 and  
39 2017). Under the environmental conditions of this study (semi-arid environments) and despite  
40 the genotypic selection of the plant material used, the different important phases of grain  
41 development (i.e., cell division, cell enlargement, and grain maturation) are affected. These  
42 physiological modifications, which are reflected in particular by a very significant limitation  
43 of the thousand kernel weight (TKW) in all of the genotypes studied, mainly result from a  
44 limitation of the grain filling time. Given these "physiologically limiting" conditions, and in  
45 total agreement with previously published results (Graybosch et al., 1995), the synthesis and  
46 accumulation of major grain constituents (i.e., storage proteins and starch) has been affected.

47 First, in this agronomic context, the accumulated storage proteins are characterized by a  
48 relatively high gliadin content [greater than 54% of the total protein content, approximately

49 10% to 15% greater than the protein content commonly encountered in soft wheat varieties  
50 (Aussenac and Rhazi, 2018)] and a very high level of polymerization/aggregation of  
51 polymeric prolamins [i.e., a high unextractable glutenin protein (UPP) content and a very high  
52 average molecular weight/average radius of gyration].

53 At the same time, a reduction in the amounts of synthesized and accumulated starch  
54 polysaccharides is accompanied by a significant change in the amylopectin/amylose ratio, the  
55 amylose content being greater than normal (i.e., >34%). Finally, the different genotypes  
56 studied are characterized by significantly different distributions of starch granules; the  
57 percentage of the volume occupied by A-type and B-type starch granules varied between  
58 genotypes for the two cropping years, confirming that the specific thermal regime during the  
59 synthesis and accumulation phases of prolamins and starch can explain the  
60 polymerization/aggregation changes in prolamins but also the modifications in the distribution  
61 of starch granules (A-type *vs.* B-type) (Park et al., 2009).

62 All of these results which, for the first time to our knowledge, make it possible to  
63 characterize the cumulative metabolism of prolamins and starch in the grains of local varieties  
64 (Lebanese) of common wheat selected for their agronomic performance, are essential in the  
65 measurement where it largely influences the aptitudes for the transformation of the  
66 corresponding flours. Indeed, as the literature shows, the different protein balances (i.e.,  
67 gliadins/glutenins, UPP content, molecular weight distribution of glutenins) (Aussenac and  
68 Rhazi, 2018) and/or starch balances (i.e., amylose/amylopectin, molecular weight distribution,  
69 granule starch distribution...) (Park et al., 2005) are responsible for the majority of the  
70 physical, physicochemical, and rheological properties essential during the stages of  
71 transformation of grain into flour and then flour into dough.

72 Following the first part (part I) devoted to the characterization of Lebanese bread  
73 wheat genotypes by studying the molecular properties of their storage proteins and their

74 starch constituents in mature grains, the second part of this study (part II) is devoted to a  
75 characterization of the rheological properties of the corresponding flours and doughs. The  
76 relationship between the molecular and rheological properties of the different wheat bread  
77 genotypes were investigated.

78

## 79 **2. Material and methods**

### 80 *2.1. Plant material*

81 The plant material consisted of four different bread wheat genotypes selected by two  
82 different agricultural research centers in dry areas ICARDA and ACSAD and tested as a  
83 substance for trials in the LARI field. The cultivars showed potential adaptation to semi-arid  
84 areas, characterized by low precipitation and high temperatures (Figure 1). The pedigrees of  
85 these cultivars were previously described (Sakr et al. 2020).

86

### 87 *2.2. Wheat flour quality traits*

88 Sieved grains from each of the three field blocks (Sakr et al. 2020) were divided into  
89 homogeneous samples. Then, samples were milled according to the AACC method (AACC  
90 26-21.02) using a Bühler laboratory miller (MLU-202, Germany). White flours were  
91 characterized through different analysis methods with at least three replicates.

92 Ash content was determined using the ICC standard method (104/1), by incineration  
93 of 5 g of flour for 1 h at 900 °C. The gluten index test was run according to the ICC  
94 standardized method (137/1) using Perten's Glutomatic machine (GM 2200; Sweden). The  
95 Zeleny sedimentation test was performed according to the ICC standard method (116/1).  
96 Hagberg falling number determination was carried out using the ICC approved method  
97 (107/1).

### 98 2.3. Rheological property determination

99 The alveograph test was applied using the AACC (54-30.1999) method and was  
100 conducted on an Alveolab machine by Chopin (Alveolab 2/2, France). Moreover, the  
101 farinograph test was applied according to the AACC standardized method (54-21.02). It was  
102 conducted on a Farinograph-E machine by Brabender (Germany). Extensography was carried  
103 out by applying the AACC method (54-10.01), using an Extensograph-E machine by  
104 Brabender (Germany).

105

### 106 2.4. Statistical analysis

107 XLSTAT (Addinsoft TM) was used for statistical analysis of data. ANOVA was used for  
108 variance comparison ( $p = 0.05$ ). Means comparisons were performed by Tukey test (HSD) ( $p$   
109  $= 0.05$ ). Due to a very large number of descriptors used to characterize the rheological (21)  
110 but also biochemical properties (24) of the flours used, a principal component analysis was  
111 used to compare these properties for the different studied wheat cultivars. During this  
112 analysis, only the figures [i.e. combination of two principal components (axes)] representing  
113 more than 70% of the total expressed variability were retained for the analysis of the results  
114 (i.e. axes F1 and F2).

115

## 116 3. Results

### 117 3.1. Wheat flour quality traits

118 Some significant differences were observed between cultivars regarding the extraction  
119 rates, ash content, gluten index, sedimentation test (Zeleny) and Hagberg number, while all  
120 genotypes presented similar wet and dry gluten contents (Table 1).

121 Regarding the extraction rates, values ranged between 60.1% and 67.6%, whereas the  
122 ash content varied between 0.61% and 0.72%. Despite the environmental constraints that



123 limited the grain filling period, resulting in a decrease in both starch accumulation and  
124 specific grain weight, the extraction rate and the ash content were very similar to those found  
125 in the literature.

126 For wet gluten, significant differences were observed among the genotypes studied,  
127 where values ranged from 39.2% to 43.2%. Whereas for dry gluten, values did not vary  
128 significantly between cultivars and ranged from 13.3% to 13.9%. These values were higher  
129 than those mentioned in the literature by some authors (Surma et al., 2012) but still supported  
130 by others (Mutwali 2011). In this latter study, the author reported wet gluten contents ranging  
131 from 26.63% to 46.94% after investigating 20 Sudanese bread wheat cultivars.

132 Significant variations between cultivars were observed regarding the gluten index.  
133 Values ranged from 55% to 68% for SHAM 8 and TAL AMARA 2, respectively, with a mean  
134 of 59%. Since the values were between 30% and 80%, the quality of the gluten obtained was  
135 considered normal (Cubadda et al. 1992). All of these observations are consistent with the  
136 results obtained by Barutcular et al. (2016), who studied the behavior of 16 different bread  
137 wheat genotypes under limiting environmental conditions (i.e., high temperature and low  
138 precipitation during grain filling) in Turkey. The gluten index values were lower under warm  
139 conditions and greater in a rainfed regime, whereas dry gluten was greater under warm  
140 conditions than in a rainfed regime.

141 For Zeleny sedimentation, values ranged from 41.0 mL to 56.9 mL, with an average of  
142 45.9 mL. TAL AMARA 2 differed statistically from other genotypes, presenting the highest  
143 value (56.9 ml). This could be explained by the fact that this genotype exhibited the highest  
144 content of glutenin. Hagberg numbers differed significantly between cultivars and ranged  
145 from 394.08 to 462.42 sec, exhibiting significantly lower alpha amylase activity (>400 sec)  
146 (Madeira et.al, 2015). These values above 250 or 300 s. show that our genotypes can be  
147 classified as high-quality seeds (Mares and Mrva, 2008).

148           Moreover, for all parameters the source of variation was mainly due to the  
149 environment, rather than the genotype [Environmental coefficient of variation ( $CV_E$ ) >  
150 Genetic coefficient of variation ( $CV_G$ )], the exception being extraction. In fact, these results  
151 are in accordance with those obtained by Surma et al. (2012), who revealed a higher  
152 environmental effect on Zeleny sedimentation and wet gluten in 24 genotypes of winter  
153 wheat, although these characteristics are influenced by genotype. Other studies also showed a  
154 greater impact of the environment on the Zeleny sedimentation value Mikhaylenko et al.,  
155 2000) and on the gluten index (Oikonomou et al. 2015).

156

### 157 *3.2. Rheological quality measured by the alveograph*

158           The four genotypes differed with respect to all alveograph parameters (Table 2). In  
159 fact, the dough strength varied from 178.25 to  $262.67 \times 10^{-4}$  joules, where Sham8 seemed to  
160 be the weakest ( $178.25 \times 10^{-4}$  joules) and KATILA the strongest ( $262.67 \times 10^{-4}$  joules).  
161 Tenacity levels (P) ranged between 55.00 (TAL AMARA 2) and 93.50 mm (KATILA),  
162 whereas those of extensibility (L) were between 68.67 and 138.25 mm (TAL AMARA 2).  
163 The extensibility index fluctuated from 42.55% to 55.33% and the swelling index (G)  
164 between 19.37% and 26.75%. However, P/L (tenacity/extensibility ratio) ranged between 0.41  
165 (TAL AMARA 2) and 1.23 (SHAM 8), with a mean ratio of 0.86. Also, genotype was the  
166 main source of variation for all alveograph parameters [Genetic coefficient of variation ( $CV_G$ )  
167 > Environmental coefficient of variation ( $CV_E$ )]. This shows a dominance of the varietal  
168 effect for this rheological test that may be involved in varietal breeding programs, revealing  
169 the possibility of predicting the value of a batch of grains from knowledge of its genetic  
170 makeup alone. These results are parallel to those obtained by Rousset et al. (1985); however,  
171 they are not in accordance with those of Surma et al. (2012), who demonstrated that the  
172 response of genotypes to different environments is unpredictable.

173

174 *3.3. Rheological quality measured by the farinograph*

175 Cultivars differed regarding all studied parameters on the farinograph (Table 3). The  
176 absorption values ranged from 58.18% to 65.26%, for TAL AMARA 2, and SHAM 8,  
177 respectively, and were almost in range with those obtained on Syrian and Turkish cultivars  
178 (Al Saleh & Brennan, 2012; Şahin et al., 2019). The peak time for the four genotypes  
179 presented a mean level of 11.40 min, where Tal Amara showed the highest level (13.03 min).  
180 This level exceeded values reported for bread wheat cultivated in the region (Al Saleh &  
181 Brennan, 2012; Şahin et al., 2019). Stability and dough weakness (12') varied, respectively,  
182 from 9.00 (SHAM 8) to 15.39 (TAL AMARA 2) min and from 42.50 (KATILA) to 98.25 BU  
183 (SHAM 8). Compared with the results of Şahin et al., (2019), stability was in range for only  
184 SHAM 8 (5.85–8.41 min), where other genotypes were higher. In addition, TAL AMARA 2  
185 and KATILA showed a higher dough strength. Moreover, variations were mostly due to  
186 genotype factor [Genetic coefficient of variation ( $CV_G$ ) > Environmental coefficient of  
187 variation ( $CV_E$ )], with the exception of peak time. These results are not in accordance with  
188 those obtained by Panozzo and Eagles (2000), who proved a superior effect of environment  
189 on the peak time, while Solomon et al. (2012) demonstrated a higher environmental effect on  
190 the farinogram of 23 genotypes grown in 12 different environments. Also, Denčić et al.  
191 (2012) demonstrated a dominant effect of genotype regarding the farinograph of 140 cultivars  
192 that originated from 28 different countries.

193

194 *3.4. Rheological quality measured by the extensograph*

195 Cultivars acted differently regarding the extensograph test (Table 4). Hence, levels of  
196 maximal resistance ranged between 203.75 and 405.25 BU for SHAM 8 and KATILA,  
197 respectively, whereas resistance to extension varied from 185.25 (SHAM 8) to 324.75 BU

198 (KATILA). Also, SHAM 8 seem to present the weaker dough and KATILA, the strongest.  
199 TAL AMARA 2 showed a higher extensibility of 200.17 mm, whereas other cultivars  
200 expressed lower values (146.50–165.42 mm). High extensibility, the weakness of SHAM 8,  
201 and the highest extensibility of TAL AMARA 2 of cultivars were revealed previously by the  
202 alveograph. Coefficient levels were between 1.13 and 2.23, but the energy values ranged from  
203 44.00 (SHAM 8) to 90.75cm<sup>2</sup> (TAL AMARA 2), confirming the weakness of SHAM 8.  
204 Under semi-dry conditions, bread wheat tended to express lower resistance to extension (160–  
205 246 BU) and energy, such as SHAM 8 (44.00 cm<sup>2</sup>) (Makawi et al., 2013). Hence, the studied  
206 cultivars might be suitable for bread making, with the exception of SHAM 8, which seemed  
207 to express weakness. Also, variations in all parameters were mainly due to the genotype factor  
208 [Genetic coefficient of variation (CV<sub>G</sub>) > Environmental coefficient of variation (CV<sub>E</sub>)]. This  
209 shows the influence of the heredity of the traits of the different cultivars on the extensograph,  
210 which is of special importance for varietal breeding programs. These results are not in  
211 accordance with those found by Denčić et al. (2012), while they agree with those of Solomon  
212 et al. (2012).

213

#### 214 **4. Discussion**

215 The main components of a wheat grain, mainly proteins, are responsible for most of  
216 the physical, physico-chemical, and rheological properties during grain processing. It is  
217 therefore important to understand and discuss the effect of environmental constraints on these  
218 components, which control all technological parameters. The environmental conditions during  
219 the two crop seasons that the lines underwent were characterized by a drastic lack of rainfall  
220 and high temperatures, particularly during the wheat grain filling phases. Although the lines  
221 were selected for their adaptation to these environments, the consequences of these  
222 particularly severe conditions were that the phases of accumulation of wheat grain reserves

223 were considerably shortened, resulting in a very low specific weight. In addition, the TKW  
224 for all genotypes was significantly affected, reflecting a reduction in the accumulation of the  
225 major components of a wheat kernel (i.e., proteins and starch). Hence, environmental  
226 conditions prevailing during both seasons of culture in our study (i.e., high temperature and  
227 negligible precipitation) during grain development reduced the grain filling length and led to  
228 modification of grain composition. In fact, high protein levels were observed, accompanied  
229 by low starch content in the grain. Also, proteins were rich in gliadins (more than 54% of total  
230 protein content), whereas a very high level of polymerization/aggregation of glutenins was  
231 revealed. At the same time, low amounts of starch were accompanied by a greater content of  
232 amylose (i.e., >34%) and a significant change in the amylopectin/amylose ratio. In addition, a  
233 significant modification of the starch granule distribution was recorded (A-type vs. B-type).

234 It is well known that temperature, rainfall, and their distribution during the growing  
235 season have a significant impact on protein quantity and distribution. Denčić et al. (2012)  
236 noted that the impact of the environment on the quality and quantity of proteins is determined  
237 by climate factors. Thus, the protein content of wheat rises in a semi-arid environment when  
238 the temperature intensity is more or less high for a long time. In addition, the combination of  
239 water scarcity and high temperatures during the grain filling phase results in an increase in  
240 protein content. Furthermore, a high temperature during the grain filling phase increases the  
241 overall amount of glutenin sub-units, whereas a water deficit increases the high molecular  
242 weight glutenin subunits/low molecular weight glutenin subunits (SG-HMW/SG-LMW) ratio  
243 (Flagella et al., 2010). Gliadin synthesis is also affected, since it has been shown that heat and  
244 water stresses cause a high accumulation of this protein fraction.

245 In addition, environmental factors control the biosynthesis and accumulation of starch in  
246 the wheat grain. Thus, water stress reduces wheat productivity by accelerating the  
247 accumulation of starch in the grain. Also, water deficit causes an alteration of the activities of

248 the enzymes involved in the synthesis of starch, which include ADP-glucose  
249 pyrophosphorylase (catalyzes the transformation of glucose-1-P into ADP-glucose) and starch  
250 synthase as well as the branching enzyme (responsible for the conversion of ADP-glucose  
251 into amylose and amylopectin) (Ahmadi and Baker, 2001). In addition, water stress alters  
252 certain characteristics of starch, such as thermal properties, bonding properties, and the  
253 number of granules produced. It causes a decrease in the accumulation of small starch  
254 granules (type B) and an increase in large granules (type A). Water stress is considered an  
255 inhibitory factor when it occurs in the second phase of starch granule development, which  
256 affects B-type granules; however, type-A granules, which develop in the first phase, are not  
257 affected by this stress (Liu et al., 2011). Also, heat stress causes morphological and physico-  
258 chemical changes in wheat starch, depending on the stage of development of the plant when it  
259 occurs. It also has an effect on starch synthesis. A temperature above 35 °C during the grain  
260 filling phase causes a decrease in starch biosynthesis due to alterations in synthetic enzymes  
261 (Thitisaksakul et al., 2012). Studies have shown that high temperatures applied after anthesis  
262 reduce the starch content of the grain and alter its composition by favoring the formation of  
263 type A granules and reducing the number of type B granules. Others have reported that  
264 temperatures above 30 °C occurring before anthesis cause a decrease in the number of A  
265 granules compared with B granules with the appearance of certain morphological deformities  
266 (Liu et al., 2011). Thus, water and heat stress affect the accumulation and composition of  
267 protein and starch in wheat grains.

268 In order to understand and interpret all of these rheological properties, which are the  
269 results of wheat grain composition being affected by the environmental constraints during  
270 both seasons of culture, a principal component analysis (PCA) comparison between these  
271 genotypes taking into consideration their rheology and composition parameters was  
272 performed (Figure 2). It showed large differences between the studied cultivars. In fact, flour

273 resulting from the obtained grains exhibited high wet and dry gluten content and Zeleny  
274 sedimentation, a low gluten index, a great extensibility on the alveograph and extensograph,  
275 and high dough strength on the farinograph. Despite the rheological modifications that  
276 occurred to the flour of cropped grains, KATILA and ACSAD 1133 seemed to be the closest  
277 in quality (Figure 2a), whereas SHAM 8 and TAL AMARA 2 differed the most from each  
278 other and from the other two genotypes in rheology as well as in composition. Thus,  
279 physiological parameters influenced the distribution of genotypes upon these two principal  
280 components (PC).

281

282 In fact, TAL AMARA 2 showed the highest extensibility, L, G, peak time, Zeleny  
283 sedimentation, and dry gluten. These parameters are generally associated with a high gliadin  
284 content and/or high protein content. Extensibility is generally explained by a high gliadin  
285 content and is also associated with the presence of the Gli-A1, Gli-B2, and Gli-D2 alleles  
286 (Branlard and Metakovsky, 2006). Recently, a very robust relationship was established  
287 between extensibility and Gli A2 (Noma et al., 2019). TAL AMARA 2 is characterized by the  
288 highest value of extensibility and has the lowest gliadin content. Therefore, its high  
289 extensibility could be explained by the quality of the glutenin aggregates obtained. The  
290 aggregates had the lowest molecular weight and the lowest polymerization index (UPP),  
291 which led to weak associations. These chemical parameters would be due to the lowest SG-  
292 HMW/SG-LMW ratio recorded among the varieties studied. A high quantity of low  
293 molecular weight glutenin subunits (SG-LMW) could be responsible for small aggregated  
294 polymers, leading to a serious modification of gluten properties, mostly those controlling the  
295 rheological characteristics of wheat grains. Regarding the Zeleny sedimentation value, which  
296 is known to be positively correlated with the protein content (Denčić et al., 2012), TAL  
297 AMARA 2 showed a relatively high protein content, but still much lower than the other

298 genotypes. However, its Zeleny value was the highest. It may be that the low protein content  
299 was compensated by its high glutenin content. Therefore, the combination of a low total  
300 protein content with a high proportion of glutenins could result in a high sedimentation value.

301 Diagonally opposite, KATILA and ACSAD had biochemical characteristics that could  
302 have allowed these two varieties a very high extensibility and a very high Zeleny value  
303 because they have accumulated a lot of proteins, especially gliadins, resulting in very high  
304 gliadines/glutenins (Gli/Glu) ratios. However, their rheological characteristics were among  
305 the lowest. This could be explained by the fact that these parameters would be influenced by  
306 the presence of a strong glutenin aggregation represented by high UPP% and that the molar  
307 mass of the polymeric aggregates is very high compared with those of TAL AMARA 2.  
308 Therefore, UPP and the molecular distribution of the polymeric aggregates would be  
309 responsible for the correction of some rheological defects. In addition, ACSAD 1133 and  
310 KATILA have been classified as PCAs based on absorption, dough strength, P, P/L, and  
311 Hagberg. These results, especially the alveograph data, can logically be explained by the high  
312 molecular weight of the polymer aggregates (Singh & MacRitchie, 2001). In addition, these  
313 rheological characteristics were due to their higher protein and gliadin content and a higher  
314 Gli/Glu ratio, as confirmed by Igbal et al. (2015). Therefore, the composition of these  
315 genotypes might favor dough extensibility counterbalanced by polymers of high molar mass  
316 and a high index of polymerization, resulting in high levels of non-extractible polymers.

317 In addition, SHAM 8 revealed higher dough weakness and a higher wet gluten  
318 content. Its wet gluten content may be attributed not only to its richness in UPP but also to the  
319 higher molar mass of its highly dispersed glutenins. The molar mass of the polymer  
320 aggregates is the highest among the studied varieties, whereas its dough weakness could be  
321 explained by the lower protein content compared to other cultivars, which is supported by  
322 Branlard and Dardevet (1985), revealing a positive correlation between dough strength and



323 protein content. Also, this weakness may be attributed to the very high molecular weight of its  
324 polymer aggregates.

325 The granular distribution of starch and molecular distribution of amylose and amylopectin  
326 could be involved in explaining certain rheological behaviors, since certain starchy molecular  
327 parameters have been strongly involved in the description of genotypes using PCA. Thus, B  
328 granules were associated with dough weakness, while C granules were linked to dry gluten as  
329 well as amylopectin content. The molar mass of amylopectin showed associations with the  
330 gluten index, extensibility, L, and G.

331 The observed results translated to a drastic effect of weather conditions on the synthesis,  
332 accumulation, polymerization, and aggregation of wheat grain reserves. This modified the  
333 grain biochemical composition and, consequently, grain dough rheological behavior, despite  
334 the potential of the studied varieties to give a yield product of high technological quality,  
335 since they contain HMW-GS 5+10 and HMW-GS 7+9.

336

## 337 **5. Conclusions**

338 Within a framework of the introduction of new varieties of bread wheat by the Lebanese  
339 State, reducing importations and locally producing grains of a suitable rheological quality in  
340 order to meet the technological requirements of preparing Lebanese bread, we have  
341 characterized the plant material selected for its adaptation to semi-arid conditions by studying  
342 its rheological behavior.

343 Although the plant material was selected, our results demonstrated that wheat grains of the  
344 studied cultivars did not express their optimal rheological potential despite technological  
345 suitability defined by their HMW-GS content (5+10), due to limitations in environmental  
346 conditions that affected the accumulation of grain components (i.e., proteins and starch) by

347 reducing the grain filling time length. Accordingly, flour resulting from the obtained grains  
348 exhibited high wet and dry gluten content and Zeleny values, a low gluten index, a great  
349 extensibility on the alveograph and extensograph, and high dough strength on the farinograph.

350 These modifications of rheological behavior of the studied grains can be explained by the  
351 grain biochemical composition, which was high in protein and low in starch content. In fact,  
352 high protein levels associated with a high gliadin content and the Gli/Glu ratio were  
353 supposedly responsible for the revealed extensibility. In addition, the high molar mass of  
354 glutenin polymers, highly aggregates, and great amounts of UPP translated to a dough of great  
355 strength. On the other hand, the rheological behavior could also be explained by low starch  
356 accumulation in the grain, which was related to elevated levels of amylose and a reduced  
357 amylopectin/amylose ratio and resulted in significant modifications in starch granule  
358 distribution, specifically a higher molecular weight of amylopectin and a higher concentration  
359 of type A vs. type B granules.

360 Thus, a comparison between flour of studied varieties cultivated during two successive  
361 years of drought revealed non-comparable rheological characteristics between the studied  
362 cultivars.

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366

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**459 Figure Captions**

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**Table 1.** Wheat flour quality traits

Genotype	Extraction rate (%)	Ash (%) (dry base)	Wet Gluten (%)	Dry Gluten (%)	Gluten Index (%)	Zeleny (mL)	Hagberg (sec)
SHAM 8	67.3b <sup>(1)</sup>	0.72c	42.78 c	13.56 a	55.00 a	41.08 a	429.17 b
TAL AMARA 2	60.1a	0.61a	40.69 b	13.92 a	68.00 c	56.92 b	421.25 b
KATILA	67.6b	0.73c	38.98 a	13.30 a	60.33 b	41.92 a	462.42 c
ACSAD 1133	67.1b	0.65b	43.98 c	13.71 a	54.00 a	43.75 a	394.08 a
Mean <sup>(2)</sup>	65.5	0.68	41.64	13.62	59.33	45.92	426.73
CV <sub>G</sub> (%)	5.51	8.73	5.33	1.92	10.81	16.15	6.59
CV <sub>E</sub> (%)	2.20	10.48	26.82	22.01	16.59	12.96	11.32

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468 <sup>(1)</sup> Multiple mean comparisons were performed using a Tukey test (HSD) ( $p = 0.05$ ).469 <sup>(2)</sup> Mean values of two consecutive cultivation years and three blocks. Genetic coefficient  
470 of variation (CV<sub>G</sub>) and Environmental coefficient of variation (CV<sub>E</sub>).

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**Table 2.** Behavior of doughs after mixing (Alveograph results)

Genotype	W × 10 <sup>-4</sup> joules	P (mm)	L (mm)	P/L	Ie (%)	G (%)
SHAM 8	178.25a <sup>(1)</sup>	84.50 c	68.67 a	1.23 d	42.55 a	19.37 a
TAL AMARA 2	230.25 b	55.00 a	138.25 d	0.41 a	55.33 c	26.75 c
KATILA	262.67 c	93.50 d	88.25 b	1.05 c	49.58 b	21.18 b
ACSAD 1133	222.75 b	75.92 b	99.75 c	0.77 b	51.72 b	21.82 b
Mean <sup>(2)</sup>	223.48	77.23	98.73	0.86	49.79	22.28
CV <sub>G</sub> (%)	12.37	21.32	29.68	41.83	10.81	14.17
CV <sub>E</sub> (%)	10.19	2.71	3.55	11.46	3.14	3.94

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473 <sup>(1)</sup> Multiple mean comparisons were performed using a Tukey test (HSD) ( $p = 0.05$ ).474 <sup>(2)</sup> Mean values of two consecutive cultivation years and three blocks. Genetic coefficient  
475 of variation (CV<sub>G</sub>) and Environmental coefficient of variation (CV<sub>E</sub>).

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**Table 3.** Behavior of flours during mixing (farinograph results)

Genotype	Absorption (%)	Peak time (min)	Stability (min)	Dough weakness 12' (UB)
SHAM 8	65.26c <sup>(1)</sup>	10.77 a	9.00 a	98.25 d
TAL AMARA 2	58.17 a	13.03 b	15.39 c	56.50 b
KATILA	65.07 c	11.10 a	15.00 c	42.50 a
ACSAD 1133	62.70 b	10.70 a	9.70 b	85.00 c
Mean <sup>(2)</sup>	62.80	11.40	12.27	70.56
CV <sub>G</sub> (%)	5.25	9.94	27.63	36.23
CV <sub>E</sub> (%)	7.33	28.12	7.89	12.15

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481 <sup>(1)</sup> Multiple mean comparisons were performed using a Tukey test (HSD) ( $p = 0.05$ ).482 <sup>(2)</sup> Mean values of two consecutive cultivation years and three blocks. Genetic coefficient483 of variation (CV<sub>G</sub>) and Environmental coefficient of variation (CV<sub>E</sub>).

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**Table 4.** Behavior of flours during mixing (extensograph results)

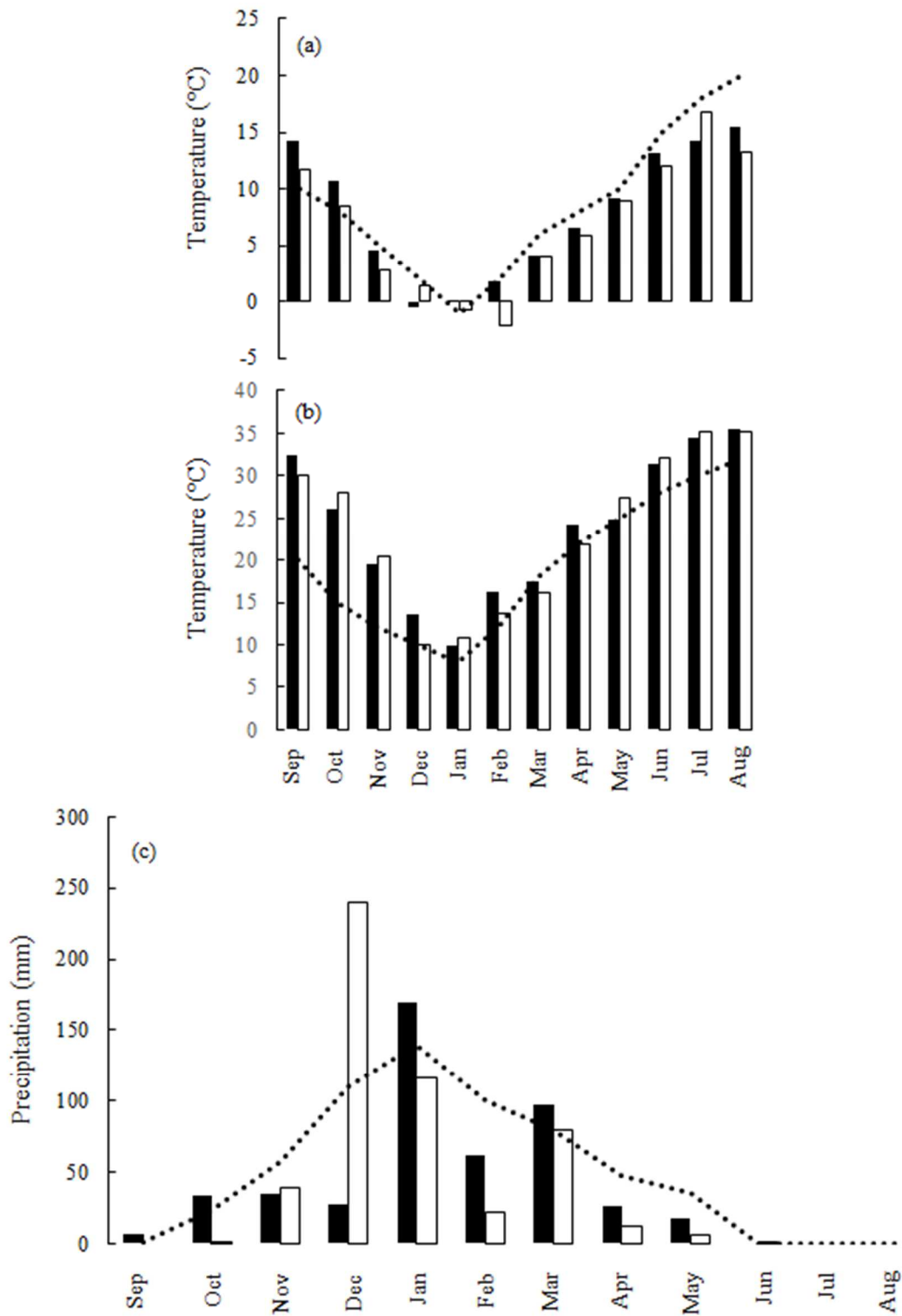
Genotype	Maximal resistance (UB)	Resistance to extension (UB)	Extensibility (mm)	Coefficient	Energy (cm <sup>2</sup> )
SHAM 8	203.75 a <sup>(1)</sup>	185.25 a	146.50 a	1.28 a	44.00 a
TAL AMARA 2	322.75 b	222.00 b	200.17 c	1.13 a	90.75 c
KATILA	405.25 d	324.75 d	147.42 a	2.23 c	90.25 c
ACSAD 1133	375.50 c	284.50 c	165.42 b	1.68 b	81.83 b
Mean <sup>(2)</sup>	326.81	254.13	164.88	1.57	76.71
CV <sub>G</sub> (%)	27.19	24.56	15.22	31.21	28.92
CV <sub>E</sub> (%)	8.03	7.58	1.97	7.85	17.59

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486 <sup>(1)</sup> Multiple mean comparisons were performed using a Tukey test (HSD) ( $p = 0.05$ ).487 <sup>(2)</sup> Mean values of two consecutive cultivation years and three blocks. Genetic coefficient488 of variation (CV<sub>G</sub>) and Environmental coefficient of variation (CV<sub>E</sub>).



**Figure 1.** Temperatures (a, b) and precipitations (c) for the two cropping seasons [2015/2016 (black bars); 2016/2017 (white bars)]. (a) monthly minimum temperatures, (b) monthly maximum temperatures. Historical averages (1954-2010) (dotted lines).



**Figure 2.** Principal component analysis (PCA) of the rheological properties and of the biochemical composition of flours of the studied cultivars.

