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Characterization of durum wheat semolina by means of a rapid shear-based method

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Abbreviations: AU, Arbitrary Units; BE, Brabender Equivalent; PMT, peak maximum time

Abstract

A rapid shear-based test - the GlutoPeak, recently proposed by Brabender GmbH & Co. (Duisburg, Germany) - was used to investigate gluten aggregation properties of durum wheat semolina and to relate them to pasta cooking behavior. Thirty semolina samples were characterized by means of the conventional approaches used for pasta-quality prediction (protein content, Gluten Index, alveographic indices). All samples were also analyzed by the GlutoPeak test obtaining three parameters: maximum peak torque, maximum peak time, area under the peak. The GlutoPeak indices were significantly correlated with protein content, Gluten Index, and W alveographic parameter. The cooking quality of pasta obtained from the 30 semolina samples was evaluated by sensory analysis in terms of stickiness, bulkiness, firmness, and overall quality. The GlutoPeak indices were significantly correlated with the sensorial parameters. In comparison with the alveographic test - presently the most used rheological approach for semolina characterization - GlutoPeak analysis presents some advantages represented by a smaller amount of sample (9g), a shorter time (less than 5 minutes) and the possibility to be carried out by untrained analysts In addition, following testing with larger sample numbers, the GlutoPeak has the potential to be used instead of the Gluten Index as a rapid and reliable approach for medium quality semolina characterisation.

Semolina from durum wheat is recognized as the most suitable raw material for dried pasta production due to the technological functionality of proteins which are unique in assuring low stickiness and good firmness to cooked pasta (D'Egidio et al 1990; Feillet and Dexter 1996). In spite of the extensive research on this topic, we are still far from the ideal test for semolina characterization. Up to now, the prediction of semolina aptitude to guarantee pasta products with optimal cooking behavior is mainly based on protein content (Feillet and Dexter 1996) and rheological approaches providing useful information for elasticity, extensibility, and resistance to overcooking (Dexter and Matsuo 1980; D'Egidio et al. 1990; Weegels et al. 1996). The rheological tests currently used for semolina characterization, together with their points of strength and weaknesses, are highlighted in Table I. Some of them are time consuming and require a large amount of sample; others are highly influenced by the analyst. Thus the development of a rapid and reliable test is still challenging.

The GlutoPeak has been recently proposed for the evaluation of flour quality from common wheat. In particular, it provides a measurement of the aggregation behaviour of gluten, as it is present in wheat flour, coarse grain or vital gluten. The test is carried out using small sample sizes (8-10 g), high flour : water ratio (about 9:10), high speed (1900-3000 rpm), and short time (< 10 minutes). Moreover, the Glutopeak does not require gluten isolation or any kind of samples handling. Up to now, the GlutoPeak supplied good indications to characterize common wheat flours (Melnyk et al. 2011; Kaur Chandi and Seetharaman 2012), while very few information is available for durum wheat products (Marti et al. 2013).

The aim of the work was to investigate the gluten aggregation properties of semolina samples different in their technological performances by this new rheological approach and the results were compared with those of the conventional approaches widely used for semolina classification. Finally, to better understand the aggregation phenomena at a molecular scale in semolina samples of different performances, we investigated the network formation at different mixing time by using an ultrastructural approach.

Materials and Methods

Samples

Thirty durum wheat semolina samples, different in protein quantity and quality, were considered in this study. Durum wheat kernels were obtained from the experimental trials of the durum wheat national network (D'Egidio et al 2013). All the durum wheat grains were milled using the same pilot milling plant (Buhuler MLU 202, Switzerland; semolina yield: 60-65%), so minimizing the differences in particle sizes related to milling conditions.

Conventional Methods

Semolina samples were characterized by means of standard methods in terms of protein content (AOAC 920.87), gluten index (ICC 158), and alveographic indices (UNI 10453).

Presently, semolina classification is based on alveographic parameters, that show a strong relationship with pasta cooking quality (D'Egidio et al 1990). On the basis of the conventional alveographic test, semolina samples were divided into three classes of quality: poor ($W<180 *10^{-4}$ J), medium ($180<W<250 *10^{-4}$ J), and good ($W>250 *10^{-4}$ J) according to the UNI 10453 standard (1995).

GlutoPeak Test

Gluten aggregation properties were measured using the GlutoPeak (Brabender GmbH and Co KG, Duisburg, Germany). An aliquot of 9 g of sample was dispersed in 10 ml of distilled water. Sample temperature was maintained at 35 °C by circulating water through the jacketed sample cup. The paddle was set to rotate at 2750 rpm and each test ran for 5 min. During the test, the sample slurry was subjected to intense mechanical action, promoted by the speed of the rotating element.

This condition allows the formation of gluten; at the same time a strong increase of the torque curve is registered. Further mixing destroys the network and the torque curve would decline.

The resulting torque curve has the typical shape shown in Fig. 1. The main indices automatically evaluated by the software are: *1)* the maximum torque (expressed in Brabender Equivalents - BE), corresponding to the peak occurring as gluten aggregates; *2)* the peak maximum time (PMT), corresponding to the time before torque falling off when gluten breaks down. In addition, the area under the peak - equivalent to energy - was calculated by integrating the curve and expressed in arbitrary unit (AU). Measurements were performed in triplicate.

Microstructural features

One poor semolina (sample 5) and one good semolina (sample 26) were chosen for a qualitative analysis of the changes in microstructural features during the test. Samples were taken at different moments, as indicated in Fig. 1: first stage of mixing (t1), after gluten formation (t2), and after its breakdown (t3) and observed by means of an Olympus BX50 microscope (Olympus, Tokyo, Japan). 0.1% toluidine blue was used for staining protein (Kirana et al. 2009).

Pasta making

Dried spaghetti were produced according to D´Egidio et al (1990). In short, semolina and water (35% dough moisture) were mixed and extruded into a spaghetti shape (1.65 mm diameter) in an experimental press (30 kg/h; Namad Press, Namad, Italy). All samples were dried in an experimental drying cell (Afrem dryer, Afrem, France) using a low temperature drying cycle (50 °C max for 14 h) and stored at room temperature until analyzed.

Sensory analysis

Sensory evaluation was carried out according to D'Egidio et al (1993). The sensory analysis was performed by a highly trained panel of 8 experts. Stickiness, the material adhering to the surface of cooked pasta, was evaluated by visual inspection with the aid of standard reference samples and by handling. Bulkiness, which is related to stickiness, measures the adhesion degree of pasta strands to each other and was evaluated both visually and manually. Firmness relates to the resistance of cooked pasta to chewing. Each parameter was scored on a 10–100 scale: 100 = absent for stickiness and bulkiness; 100 = very good for firmness. The score of each sensory judgment component was the mean of the values given by the panelists. The overall score was the average of the means for stickiness, bulkiness, and firmness.

Statistical analysis

Data were processed by Statgraphic Plus for Windows v. 5.1. (StatPoint Inc., Warrenton, VA, USA) and significant correlations were performed adopting the Pearson correlation analysis procedure.

Results and Discussion

GlutoPeak and conventional tests

Results for the conventional parameters (protein content, Gluten Index, W alveographic) and the new ones (maximum torque, peak maximum time, and energy, calculated from the GlutoPeak curve) for semolina characterisation are shown in Table II, in which mean, standard deviation, and coefficient of variation for each sample were reported. The Alveographic test exhibited the highest variability among the rheological approaches. The coefficient of variation for the W alveographic ranged from 16.7 to 2.5, with a median value of 5.4. As regard the coefficients of variation of Gluten Index, they were in the 0.7-9% range, with a median of 1.99%. The indices obtained from the Glutopeak test exhibited the lowest variability: the maximum coefficient of variation for the maximum torque, the peak maximum time, and the energy were 2.6, 5.6, and 4.2%, respectively; median values for these indices were 0.7, 0, and 1.1, respectively. These results suggested that the new approach exhibited higher repeatability than the conventional tests.

All the samples showed a peak between 90 and 158 seconds, except sample 9 and 10 which did not exhibit a peak until 10 minutes of analysis, suggesting poor gluten aggregation properties in the hydration conditions used in this study. Based on the alveographic index, sample 9 and sample 10 are classified in poor quality category. Pasta samples prepared from these two samples exhibited high stickiness and high bulkiness after cooking (Table III). The cooking behavior was in accordance with the GlutoPeak results and their interpretation: the poor gluten aggregation capacity of semolina samples resulted in a scarce capacity to keep starch granules inside the protein matrix. On the contrary, the Gluten Index test was not able to highlight the low quality of samples 9 and 10. However, both samples exhibited an aggregation peak when a less diluted slurry (9 g sample in 9 g water) was used (data not shown), highlighting the capability to form a network, as indicated by the conventional methods.

Considering the whole sample set (n=30), a significant positive correlation between protein content, maximum torque ($r = 0.54$, $p < 0.01$) and the area under the curve (energy) was observed ($r = 0.47$, $p < 0.01$; Table IV). As for the quality of gluten, the statistical analysis showed significant positive correlations between W alveographic and peak maximum time ($r = 0.35$; $p < 0.05$) and maximum torque ($r = 0.56$, $p < 0.01$). The energy was significantly correlated both to the Gluten Index ($r = 0.47$, $p < 0.01$) and W alveographic ($r = 0.65$, $p < 0.01$). suggesting that samples characterized by strong gluten required high energy to aggregate into a cohesive matrix.

According to the Gluten Index test, all the samples with a value higher than 80 fall within the good quality category, based on W alveographic index (UNI 10453, 1995) (Fig 2a). Sample 14 - with a low W value (W=182) exhibited a very high GI value (GI = 87). Semolina 1, 2, 3, 6, and 7 with a $GI<50$ correctly fall in the poor quality class. Whereas, samples 4, 5, 9, and 10 showed medium GI values ($67<GI<70$) even if , according to the present Italian classification method, they belong to the poor quality class ($W<180$). Moreover, noteworthy samples 2 and 9 had similar protein content and W index but a very different Gluten Index (42 and 67, respectively).

The GlutoPeak was able to distinguish the samples of high quality (area> 2400 AU) from those of low quality (area <2400 AU) (Fig 2b). As expected, medium quality semolina exhibited an intermediate behaviour. In particular, these latter can be divided in two groups: the first one with area < 2400 AU (samples 11, 16, 18, and 19), and a second one with area > 2400 AU (samples 12, 13, 14, 15, 17, and 20). Most of the samples belonging to the latter group exhibited good pasta quality attributes (Table III). Summarizing, both the approaches (GlutoPeak and Gluten Index) correctly discriminate samples of high quality from those of very poor quality. Whereas, the output is not univocal in the case of medium quality samples (Gluten Index in the 30-65 range).

Microstructural features of semolina during GlutoPeak test

Microscopic images of poor (sample 5) and good quality (sample 26) semolina sample taken in three subsequent moments during the test are shown in Fig. 3. The gluten aggregation properties showed strong differences since from the first stages of mixing. The higher protein content of semolina of good quality (13.1%) compared with that of poor quality (12.2%), together with the different protein quality shown by conventional tests (sample 5 exhibited lower Gluten Index and W alveographic index compared with sample 26), explains the ability to quickly create protein agglomerates in good quality semolina (Fig. 3 a,c), compared to sample 5 (Fig. 3 b,d). When gluten aggregation was completed, the maximum torque was recorded by the instrument, and the formation of a well-structured network characterized by long protein fibrils surrounding starch granules was recognizable. The higher the semolina quality, the more thick and continuous is the protein network (Fig. 3 c). The prolonged mixing at high speed causes an inevitable rupture of the protein network (Fig. 3e, f). This phenomenon is particularly evident when the protein quality of semolina is poor (Fig. 3 f). For the good quality semolina sample, in fact, the protein network continues to show a continuous structure even after more than two minutes of mixing (Fig. 3 e).

GlutoPeak and pasta quality

The results of sensory evaluation of cooked pasta prepared from semolina samples are reported in Table III. The energy required for gluten aggregation, as reported above (Table II), was calculated as the area under the curve; for this reason the energy values consider both the peak maximum time and the maximum peak torque, and it seems to be an important complimentary index that provides additional information. The correlation coefficients for the semolina samples are shown in Table V. When all the thirty samples were considered, the maximum torque was significantly ($p<0.01$) correlated with stickiness ($r=0.55$), bulkiness ($r=0.42$), and the overall quality ($r = 0.38$) of cooked pasta. As regard the energy, it was significantly ($p<0.01$) correlated with stickiness ($r = 0.56$), bulkiness ($r = 0.50$), and the overall quality ($r = 0.49$) of cooked pasta. Semolina presenting high GlutoPeak energy values gave a product characterized by low stickiness and bulkiness. These results confirmed that raw materials with good aggregation properties (high torque during the test) resulted in a product with high overall quality. In the conditions used in this study, none of the GlutoPeak indices was significantly correlated to the firmness of the cooked pasta (Table V).

Since it was noticed (Fig 2) that one of the weakness of the Gluten Index tests was the low capacity of discriminating semolina of medium quality, correlation was carried out also taking into consideration only the samples with a Gluten Index in the 30-65 range (Table V). For this set, the Gluten Index did not show any significant correlation with any of the pasta quality attributes. Moreover, the correlation between W alveographic and pasta sensory quality was less strong (firmness) or even not significant (stickiness, bulkiness, and overall score). Whereas, the significant correlation between the GlutoPeak parameters and stickiness and bulkiness is of significant importance, since these two attributes are often difficult to be predicted.

Conclusions

Overall, the results obtained from the screening of 30 durum wheat semolina samples are encouraging in showing GlutoPeak as a fast and reliable approach for semolina characterization.

GlutoPeak indices were significantly correlated with the conventional parameters used for semolina characterization and pasta-quality prediction, with the advantages of requiring few minutes of analysis (less than 5 minutes) and small amount of sample (9 g), properties of great interest in all sectors of durum wheat transformation chain. Moreover, the results obtained using the GlutoPeak are encouraging to propose this new approach as a valid screening tool for durum wheat quality.

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277 **Table I**

278 **Rheological approaches currently used for semolina characterization**

279 * including sample preparation and cleaning

Test	Principle	Time required*	Sample amount required	Influence of the analyst
Gluten Index Method	It measures the amount of wet gluten remaining on a specially constructed sieve after centrifugation under standardized conditions (ICC 158, AACC 38-12)	~15 min	10 g	high
Glutograph Test	It measures the extensibility and elasticity of washed wet gluten, isolated from flour (Sietz 1987; Alamri et al.,2009)	~15 min	10 g	very high
Alveographic Test	It measures resistance to 3-D extension of a thin sheet of dough, prepared at a constant hydration level (43.3%) (Faridi & Rasper 1987; D'Egidio et al., 1990)	~50-60 min	250 g	very high
Mixolab Test	It measures changes in consistency of dough subjected to the simultaneous action of mixing and temperature (Dubat 2013; D'Egidio et al., 2013)	~50-60 min	50 g	low

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Table II

Semolina characteristics

Semolina samples	Conventional quality indices			GlutoPeak indices		
	Protein (g/100g db)	Gluten Index	W alveographic (*10^{-4} J)	Maximum torque (BE)	Peak maximum time (s)	Energy (AU)
1	10.9 ± 0.04 (CV=0.3%)	31 ± 2.8 (CV=9.1%)	135 ± 19.7 (CV=14.7%)	26.5 ± 0.7 (CV=2.7%)	85.0 ± 1.4 (CV=1.7%)	1899 ± 40.2 (CV=2.1%)
2	12.2 ± 0.04 (CV=0.3%)	42 ± 2.8 (CV=6.7%)	92 ± 5.3 (CV=5.8%)	27.0 ± 0 (CV=0%)	107.5 ± 0.70 (CV=0.7%)	1749 ± 26.1 (CV=1.5%)
3	10.9 ± 0.01 (CV=0.1%)	50 ± 2.1 (CV=4.3%)	146 ± 20.1 (CV=13.8%)	23.0 ± 0 (CV=0%)	133.5 ± 0.7 (CV=0.5%)	2395 ± 27.6 (CV=1.1%)
4	11.2 ± 0.05 (CV=0.4%)	57 ± 1.4 (CV=2.5%)	150 ± 16.9 (CV=11.2%)	28.5 ± 0.7 (CV=2.5%)	94.0 ± 0 (CV=0%)	2303 ± 27.6 (CV=1.1%)
5	12.2 ± 0.02 (CV=0.2%)	70 ± 0.71 (CV=1%)	120 ± 5.1 (CV=4.2%)	26.5 ± 0.7 (CV=2.7%)	95.5 ± 0.7 (CV=0.7%)	2097 ± 65.6 (CV=3.1%)
6	10.8 ± 0.06 (CV=0.6%)	45 ± 1.4 (CV=3.1%)	107 ± 4.9 (CV=4.6%)	25.0 ± 0 (CV=0%)	152.5 ± 2.1 (CV=1.4%)	2277 ± 59.5 (CV=2.6%)
7	12.7 ± 0.03 (CV=0.2%)	48 ± 0.71 (CV=1.5%)	126 ± 6.6 (CV=5.3%)	34.0 ± 0 (CV=0%)	79.0 ± 1.4 (CV=1.8%)	1899 ± 11.6 (CV=0.6%)
8	10.9 ± 0.05 (CV=0.5%)	68 ± 2.8 (CV=4.2%)	146 ± 17.7 (CV=11.8%)	27.0 ± 0 (CV=0%)	129.0 ± 1.4 (CV=1.1%)	2729 ± 8.9 (CV=0.33%)
9	12.3 ± 0.11 (CV=0.9%)	67 ± 0.71 (CV=1.1%)	92 ± 4.4 (CV=4.8%)	-	-	-
10	10.8 ± 0.11 (CV=1%)	70 ± 1.4 (CV=2%)	126 ± 3.2 (CV=2.5%)	-	-	-
11	12.8 ± 0.03 (CV=0.2%)	72 ± 2.1 (CV=3%)	211 ± 7.2 (CV=3.4%)	29.0 ± 0 (CV=0%)	99.5 ± 0.7 (CV=0.7%)	2170 ± 0.1 (CV=0%)
12	13.0 ± 0.06 (CV=0.4%)	78 ± 2.1 (CV=2.7%)	223 ± 12.1 (CV=5.4%)	27.5 ± 0.7 (CV=0.6%)	117.0 ± 1.4 (CV=1.2%)	2646 ± 26.5 (CV=1%)
13	13.8 ± 0.06 (CV=0.5%)	70 ± 0.71 (CV=0.5%)	242 ± 12.3 (CV= 5.1%)	32.5 ± 0.7 (CV=2.2%)	105.5 ± 0.7 (CV=0.7%)	2679 ± 96.7 (CV=3.6%)
14	13.3 ± 0.01 (CV=0.1%)	87 ± 1.4 (CV=1.6%)	182 ± 11.8 (CV=6.5%)	24.5 ± 0.7 (CV=2.9%)	133.0 ± 1.4 (CV=1.1%)	2836 ± 118.9 (CV=4.2%)
15	12.0 ± 0.02 (CV=0.2%)	72 ± 1.4 (CV=2%)	221 ± 10.4 (CV=4.7%)	25.5 ± 0.7 (CV=2.8%)	141.5 ± 0.7 (CV=0.5%)	2495 ± 15.9 (CV=0.64%)
16	13.2 ± 0.06 (CV=0.4%)	61 ± 3.5 (CV=5.8%)	219 ± 9.3 (CV=4.3%)	32.0 ± 0 (CV=0%)	91.5 ± 0.7 (CV=0.8%)	1918 ± 6.2 (CV=0.32%)
17	12.4 ± 0.04 (CV=0.3%)	80 ± 3.5 (CV=4.4%)	215 ± 21.6 (CV=10%)	24.0 ± 0 (CV=0%)	156.0 ± 1.4 (0.9%)	2909 ± 32.7 (CV=1.1%)
18	12.6 ± 0.01 (CV=0.1%)	54 ± 3.5 (CV=6.6%)	220 ± 12.2 (CV=5.5%)	29.5 ± 0.7 (CV=2.4%)	90.0 ± 0 (CV=0%)	2212 ± 23.9 (CV=1.08%)
19	13.9 ± 0.03 (CV=0.2%)	74 ± 1.4 (CV=1.9%)	191 ± 15.1 (CV=7.9%)	33.0 ± 0 (CV=0%)	100.0 ± 0 (CV=0%)	2274 ± 22.6 (CV=1%)
20	13.8 ± 0.06 (CV=0.5%)	62 ± 2.8 (CV=4.6%)	206 ± 10.6 (CV=5.1%)	35.0 ± 0 (CV=0%)	95.5 ± 0.7 (CV=0.7%)	2396 ± 12.4 (CV=0.5%)
21	14.1 ± 0.05 (CV=0.4%)	95 ± 0.71 (CV=0.7%)	369 ± 46.5 (CV=12.6%)	28.5 ± 0.7 (CV=2.5%)	158.5 ± 3.5 (CV=2.2%)	3641 ± 2.7 (CV=0.07%)
22	15.0 ± 0.1 (CV=0.7%)	91 ± 2.1 (CV=2.3%)	411 ± 20.3 (CV=4.95)	36.5 ± 0.7 (CV=1.9%)	111.5 ± 2.1 (CV=1.9%)	3052 ± 29.7 (CV=0.97%)
23	13.0 ± 0.11 (CV=0.9%)	84 ± 1.4 (CV=1.7%)	303 ± 8.8 (CV=2.9%)	29.0 ± 0 (CV=0%)	121.5 ± 2.1 (CV=1.7%)	2759 ± 70.1 (CV=2.5%)
24	13.4 ± 0.07 (CV=0.5%)	93 ± 1.41 (CV=1.5%)	346 ± 57.9 (CV=16.7%)	34.5 ± 0.7 (CV=2.0%)	103.5 ± 0.7 (CV=0.7%)	3076 ± 3.8 (CV=0.12%)
25	13.8 ± 0.06 (CV=0.4%)	90 ± 1.4 (CV=1.6%)	279 ± 16.4 (CV=5.9%)	34.0 ± 0 (CV=0%)	104.5 ± 0.7 (CV=0.7%)	2552 ± 7.4 (CV=0.29%)
26	13.1 ± 0.12 (CV=0.9%)	97 ± 0.71 (CV=0.7%)	363 ± 19.3 (CV=5.3%)	35.0 ± 0 (0%)	101.0 ± 1.4 (CV=1.4%)	2603 ± 6.9 (CV=0.27%)
27	13.6 ± 0.12 (CV=0.9%)	86 ± 2.83 (CV=3.3%)	333 ± 23.86 (CV=7.2%)	34.0 ± 0 (CV=0%)	95.5 ± 0.7 (CV=0.7%)	2472 ± 91.9 (CV=3.7%)
28	13.5 ± 0.08 (CV=0.6%)	89 ± 0.71 (CV=0.8%)	313 ± 29.56 (CV=9.4%)	37.5 ± 2.1 (CV=5.7%)	124.0 ± 0 (CV=0%)	2562 ± 88.9 (CV=3.5%)
29	13.7 ± 0.07 (CV=0.5%)	80 ± 1.4 (CV=1.8%)	290 ± 14.8 (CV=5.1%)	31.5 ± 0.7 (CV=0.2%)	109.0 ± 2.8 (CV=2.2%)	2556 ± 99.6 (CV=3.9%)
30	13.5 ± 0.11 (CV=0.8%)	90 ± 0.71 (CV=0.8%)	296 ± 14.1 (CV=4.8%)	28.0 ± 0 (CV=0%)	151.0 ± 0 (CV=0%)	3217 ± 50.11 (CV=1.56%)

BE, Brabender Equivalent; AU, Arbitrary Units

Table III

Sensory quality of pasta samples

Semolina samples	Pasta sensory quality			
	Stickiness	Firmness	Bulkiness	Overall score*
1	60.0±2.5	60.0±2.5	60.0±2.5	60.0±2.5
2	50.0±2.5	60.0±2.5	50.0±2.5	53.3±2.5
3	35.0±7.5	60.0±4.2	40.0±2.5	45.0±4.2
4	40.0±2.5	60.0±2.5	43.0±7.5	47.8±7.5
5	50.0±2.5	60.0±2.5	50.0±2.5	53.3±2.5
6	40±2.5	60.0±2.55	43.3±7.5	47.8±4.2
7	50.0±2.5	50.0±2.5	50.0±2.5	50.0±2.5
8	43.3±7.5	65.0±7.5	43.3±7.5	50.5±5.0
9	40.0±2.5	70.0±4.5	45.0±7.5	51.7±4.2
10	40.0±2.5	71.7±5.0	45.0±7.5	52.2±5.0
11	50.0±2.5	60.0±2.5	50.0±2.5	53.3±2.5
12	55.0±7.5	63.3±7.5	55.0±7.5	57.8±7.5
13	50.0±2.5	60.0±2.5	50.0±2.5	53.3±2.5
14	60.0±2.5	70.0±2.5	60.0±2.5	63.3±2.5
15	40.0±2.5	70.0±2.5	40.0±2.5	50.0±2.5
16	50.0±2.5	70.0±2.5	50.0±2.5	56.7±2.5
17	50.0±2.5	60.0±2.5	53.3±5.0	54.4±3.3
18	50.0±2.5	60.0±2.5	55.0±7.5	55.0±4.2
19	53.3±7.5	70.0±2.5	50.0±2.5	57.8±4.2
20	60.0±2.5	63.3±7.5	56.7±7.5	60.0±5.8
21	70.0±2.5	70.0±2.5	70.0±2.5	70.0±2.5
22	65.0±7.5	73.3±5.0	63.3±7.5	67.2±5.8
23	60.0±2.5	75.0±7.5	60.0±2.5	65.0±4.2
24	60.0±2.5	70.0±2.5	60.0±2.5	63.3±2.5
25	60.0±2.5	66.7±7.5	56.7±7.5	61.1±5.8
26	53.3±7.5	63.0±7.5	55.0±7.5	57.2±7.5
27	60.0±2.5	70.0±2.5	60.0±2.5	63.3±2.5
28	56.7±7.5	73.3±7.5	55.0±7.5	61.7±7.5
29	55.0±7.5	70.0±2.5	50.0±2.5	58.3±4.2
30	55.0±7.5	80.0±2.5	55.0±7.5	63.3±5.8

** The overall score is the average of the means for stickiness, bulkiness, and firmness.*

Table IV

Correlation coefficients of Glutopeak and conventional indices

	Peak maximum time	Maximum torque	Energy	Protein	Gluten index	W Alveographic
Peak maximum time	1					
Maximum torque	0.56**	1				
Energy	0.88**	0.75**	1			
Protein	n.s.	0.54**	0.47**	1		
Gluten index	n.s.	n.s.	0.47**	0.69**	1	
W Alveographic	0.35*	0.56**	0.65**	0.75**	0.80**	1

* $p<0.05$
** $p<0.01$
n.s., not significant

Table V

Correlation coefficients of pasta quality attributes and rheological indices

	Stickiness		Firmness		Bulkiness		Overall score	
	All samples (n=30)	Samples with 30<GI<65 (n=9)	All samples (n=30)	Samples with 30<GI<65 (n=9)	All samples (n=30)	Samples with 30<GI<65 (n=9)	All samples (n=30)	Samples with 30<GI<65 (n=9)
Gluten Index	0.52***	n.s.	0.65***	n.s.	0.50***	n.s.	0.65***	n.s.
Maximum torque	0.55***	0.60**	n.s.	n.s.	0.42***	0.49*	0.38**	0.51*
Peak maximum time	n.s	-0.66**	n.s.	n.s.	n.s.	-0.67***	n.s.	-0.59**
Energy	0.55***	n.s.	n.s.	n.s.	0.50***	n.s.	0.49***	n.s.
W Alveographic	0.69***	n.s.	0.54***	0.55*	0.68***	n.s.	0.76***	n.s.

* p<0.1
** p<0.05
*** p<0.01
n.s., not significant

Fig. 1 Curve of semolina sample produced by GlutoPeak software during a test. The variables of importance are highlighted: maximum torque, peak maximum time, and area under the peak. t1, t2, and t3 represent the sampling times for microscopic observations.

Fig. 2 Semolina classification: ability of Gluten Index (a) and GlutoPeak curve area (b) to discriminate semolina samples according to the current method based on W alveographic index. A.U., Arbitrary Unit

Fig. 3 Microscopic images of good (A, C, E) and poor (B, D, F) quality semolina at first stage of mixing (A, B), after gluten formation (C, D), and after its breakdown (E, F).

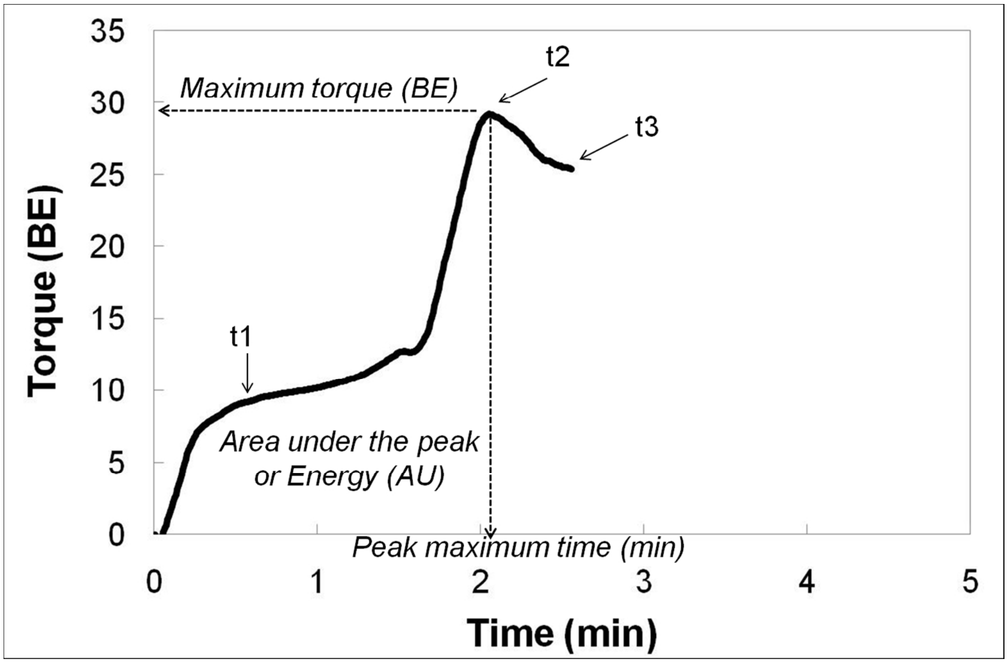


Fig. 1 Curve of semolina sample produced by GlutoPeak software during a test. The variables of importance are highlighted: maximum torque, peak maximum time, and area under the peak. t1, t2, and t3 represent the sampling times for microscopic observations.
245x160mm (150 x 150 DPI)

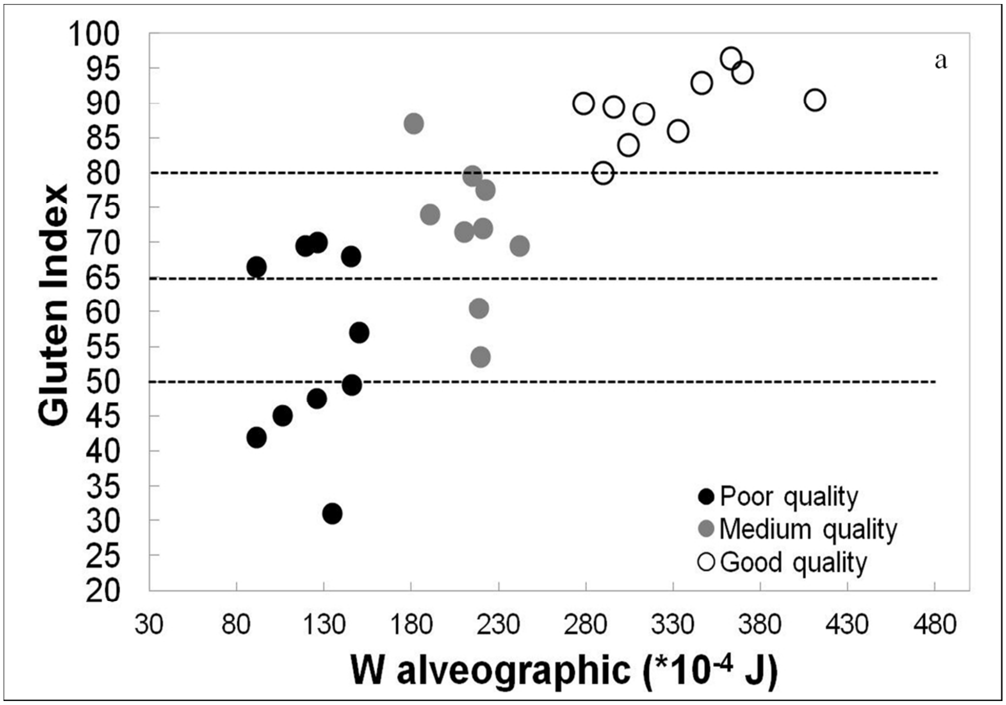
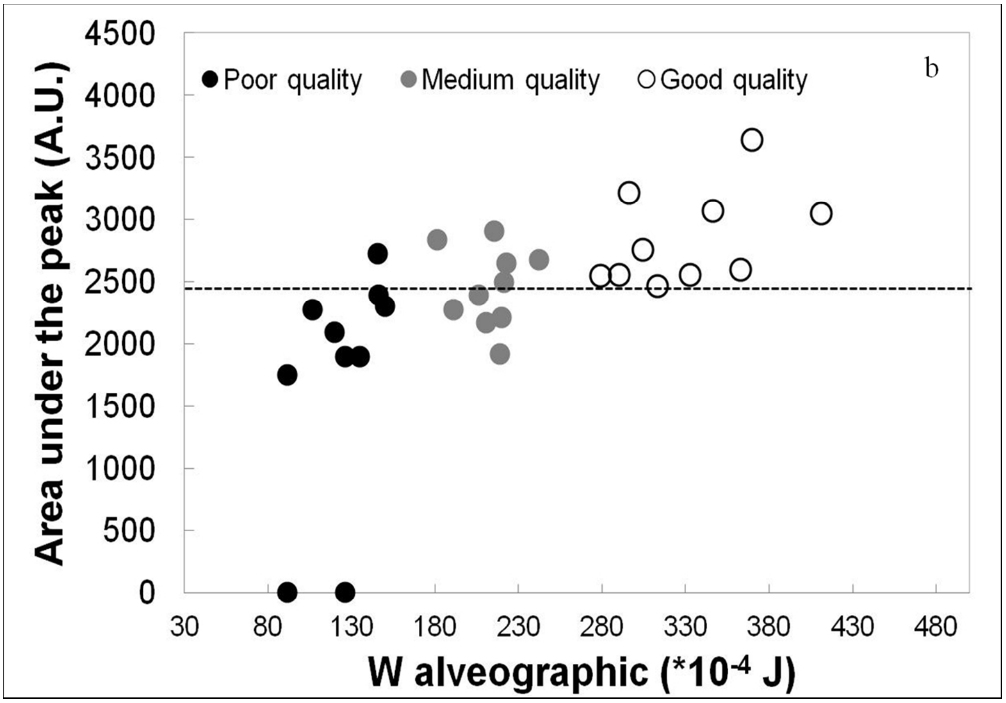


Fig. 2 Semolina classification: ability of Gluten Index (a) and GlutoPeak curve area (b) to discriminate semolina samples according to the current method based on W alveographic index.
A.U., Arbitrary Unit

216x150mm (150 x 150 DPI)



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A.U., Arbitrary Unit
216x150mm (150 x 150 DPI)

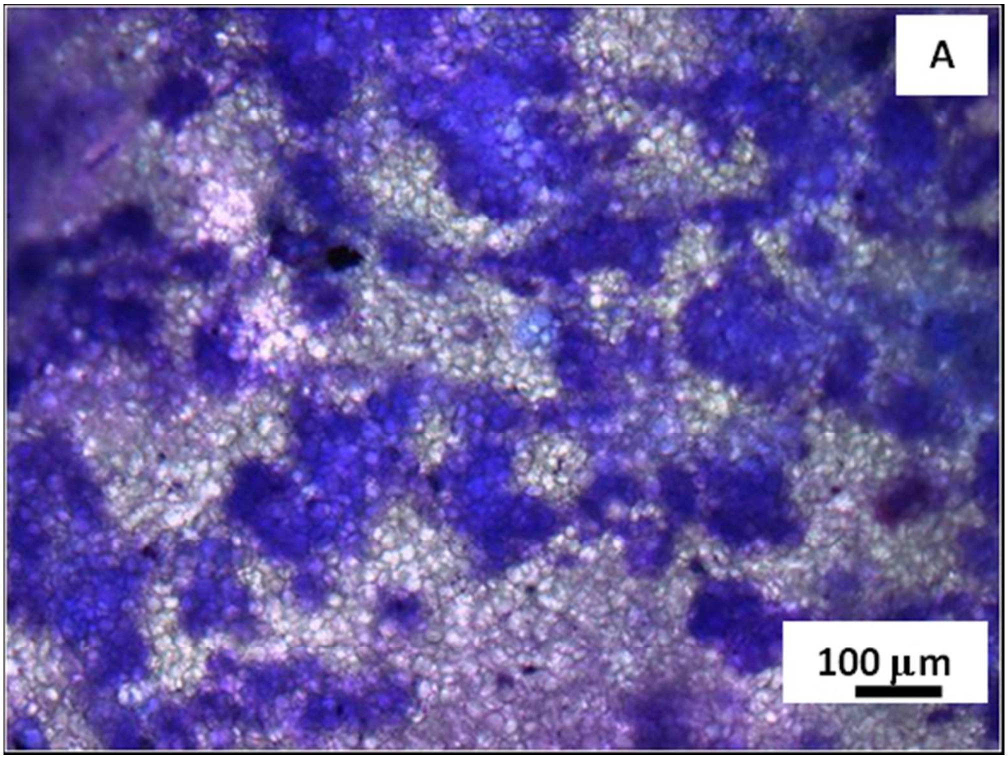
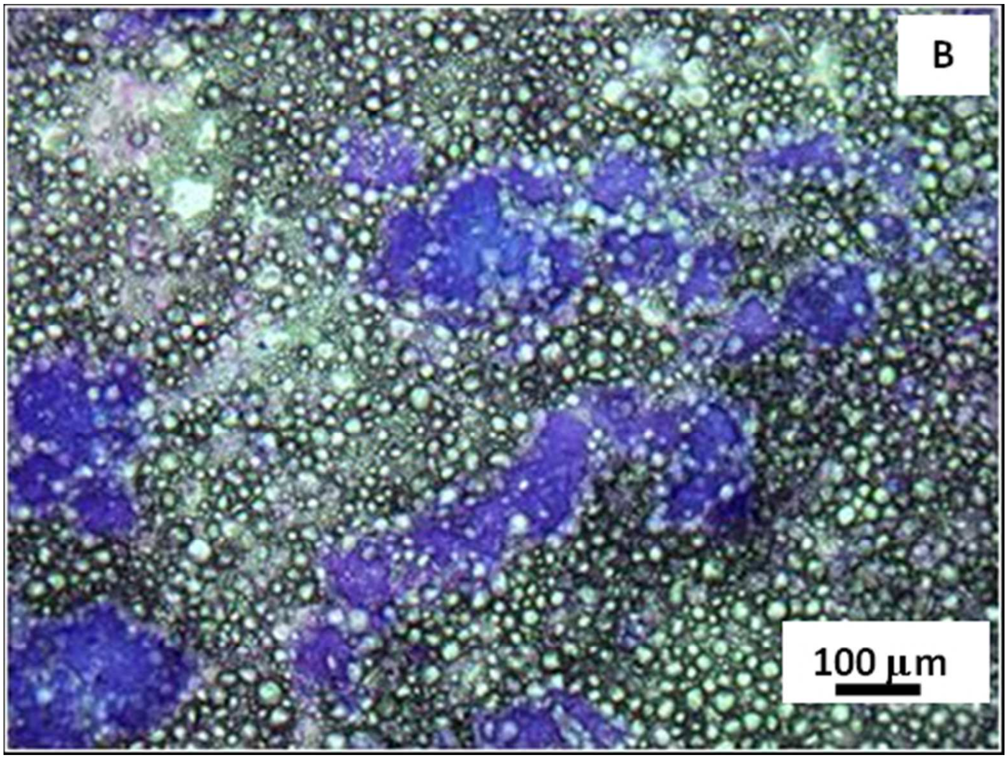


Fig. 3 Microscopic images of good (A, C, E) and poor (B, D, F) quality semolina at first stage of mixing (A, B), after gluten formation (C, D), and after its breakdown (E, F).
86x65mm (150 x 150 DPI)



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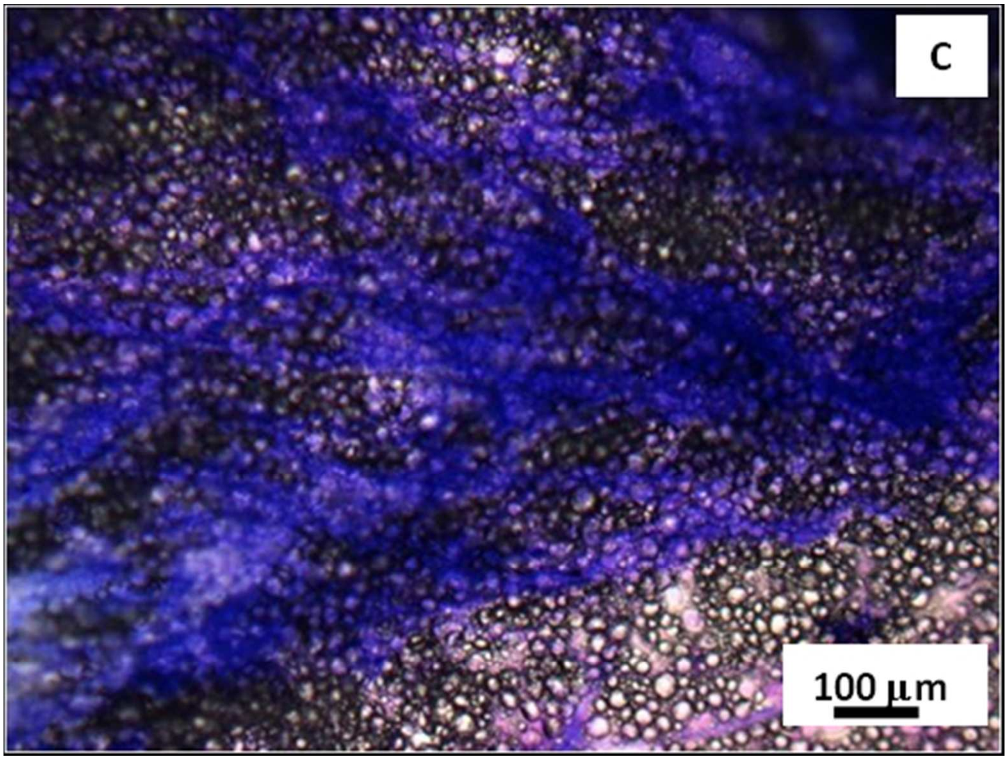
86x65mm (150 x 150 DPI)



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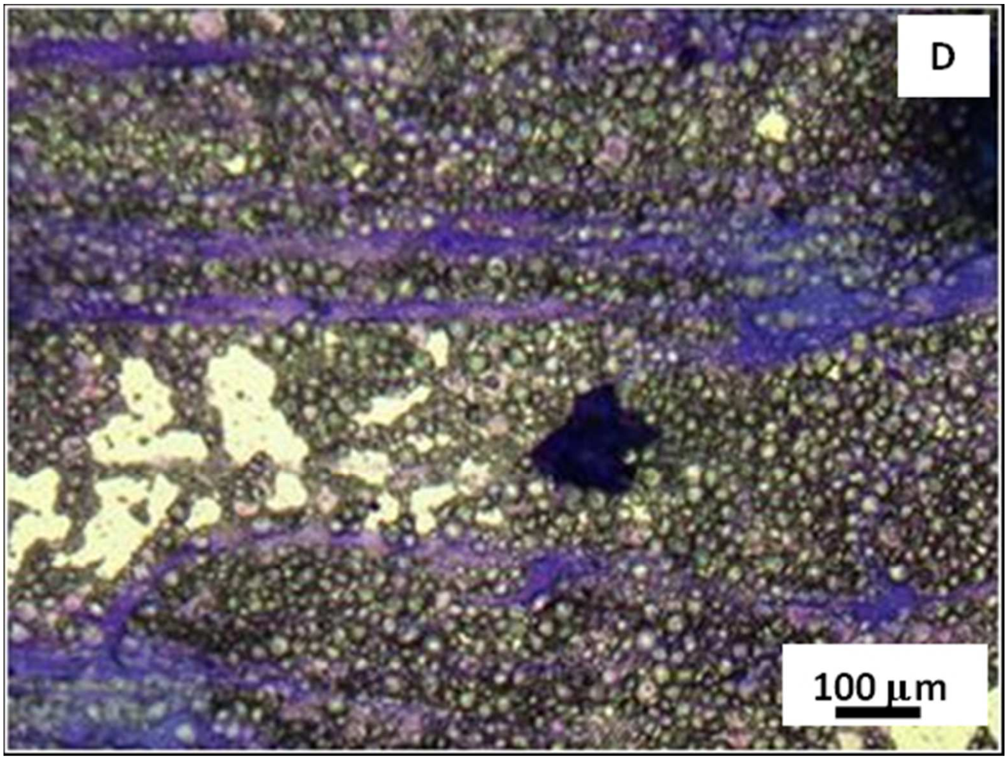

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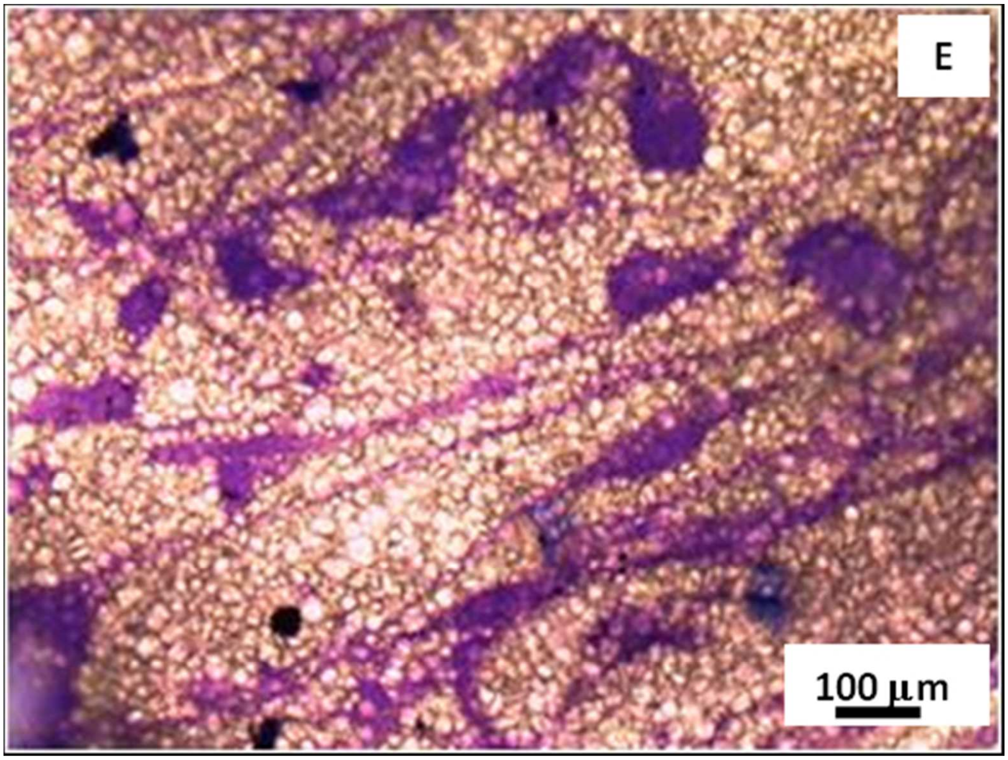
86x65mm (150 x 150 DPI)



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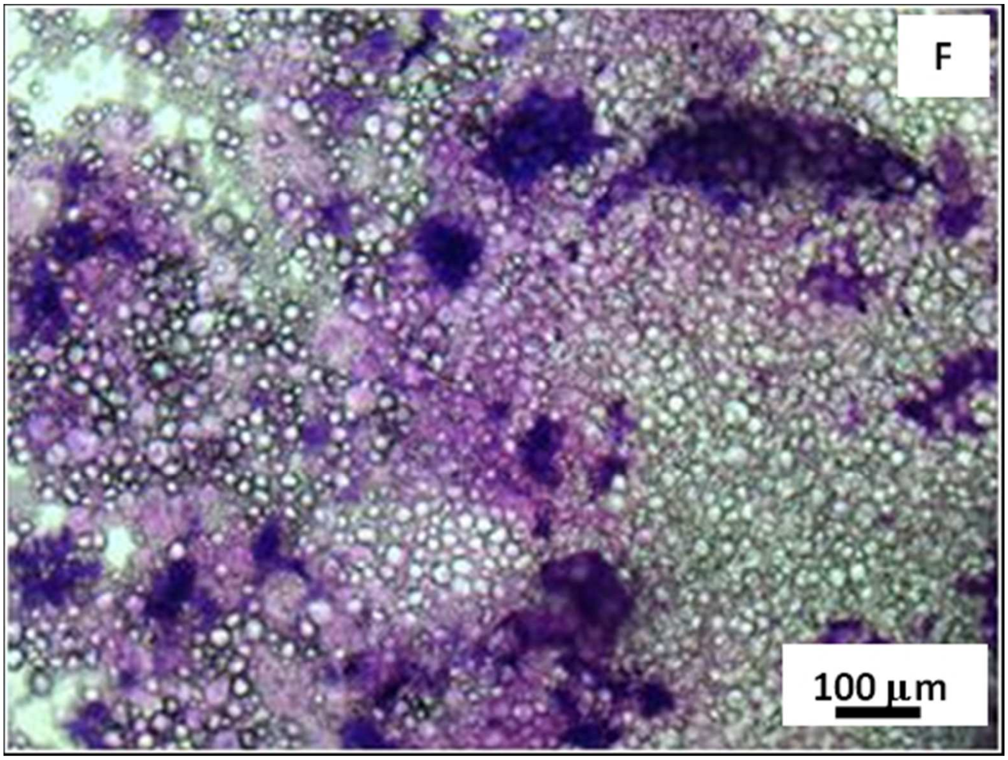

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86x65mm (150 x 150 DPI)