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Utilization of Mixolab for assessment of durum wheat quality dependent on climatic factors

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ABSTRACT

For durum wheat quality assessment the commonly used parameters are protein content, yellow pigment content, hectoliter mass, grain vitreousness, 1000- grain weight and sodium dodecyl sulphate sedimentation. For wheat processing quality, in this study the Mixolab, instrument of a newer generation was used. Mixolab has been largely used for a rapid assessment of the *Triticum aestivum* quality but there is no a lot of data about durum wheat quality assesment. Therefore, the aim of this work was to test its potential in the quality characterization of fourteen durum wheat breeding lines grown during two production years with different climate conditions. The obtained results showed significant differences in starch-amylase complex part of Mixolab curve between two studied years. Mixolab parameters C3, C4 and C5 were in line with Falling number values and amylolytic activity of samples. Samples from 2013 production year with higher precipitation sum had lower values of C3, C4 and C5 parameters as well as Falling number values and higher amylolytic activity. On contrary, protein part of Mixolab curves expressed differences in dependence of genotype. In comparison to the standard parameters of protein and starch quality of durum wheat, Mixolab provides more complete information in a shorter time frame.

1. Introduction

Durum wheat (*Triticum durum*) is grown worldwide forming 5–9% share in the global wheat crop. Durum wheat cultivation is not widespread when compared to bread wheat, due to low yield as well as special requirements regarding agro technical processes and climatic factors. Nevertheless, it is evident that interest in growing this kind of wheat still exists, because of its value as a staple in pasta-making industry, as well as bread staple. One more factor to be taken into account is consumers' increasing demands for high quality food (Sapirstein et al., 2007; Branković et al., 2014).

Durum wheat represents the most suitable raw material for the production of pasta thanks to its specific characteristics that positively affect the quality of the end product in terms of adhesion, hardness, the product color and the loss of dry matter in cooking pasta. The most important quality factors include a high content of protein, starch, the presence of a yellow pigment that gives the pasta its characteristic color and proportion of grain vitreousness. All of these quality parameters are strongly influenced by the durum wheat variety (Branković et al., 2014). The high level of quality standard uniformity of different varieties of durum wheat is of great importance for pasta making industry. However, the genotypes quality as well as other qualitative characteristics is subject to changes that occur as a consequence of changed climate conditions. There are numerous studies in which main research aims were to examine the impact of the particular wheat variety, climatic factors and their interactions on the quality of certain durum wheat quality parameters (Guasconi et al., 2011; Pinheiro et al., 2013; Ferrise et al., 2015). Rharrabti et al. (2003) examined the impact of climate conditions, genotype and their interaction on certain quality parameters of durum wheat and came to the conclusion that the dominant influence of climatic factors is evident in protein content, kernel vitreousness and 1000-grain weight. In the case of Sodium dodecyl sulphate (SDS) sedimentation values and yellow pigment content, in addition to climate impacts there is also a considerable influence of genotype. This is not surprising since SDS sedimentation values indicate on quantity and quality of wheat proteins for which is well known that are conditioned by the genotype (AbuHammad et al., 2012). On the other hand, Pinheiro et al. (2013) reported that SDS sedimentation value of the examined durum wheat genotypes did not show significant dependence on climatic factors.

Durum wheat quality is determined by a number of factors that contribute to its variation (lower protein content, too much damaged starch in milling process, wide range in semolina particle size, higher enzyme activity), therefore understanding of their roles is necessary in order to overcome the problems in wheat processing (higher content of water in the beginning the drying process, increased cooking loss and decreased firmness of final product). Commonly used methods for assessing the quality of durum wheat are wet and dry gluten content, sedimentation, as well as yellow pigment content. To assess the quality of the durum wheat protein, there are modified methods that are commonly used to evaluate the quality of bread wheat (alveograph, mixograph, farinograph, gluten index, glutograph). De Angelis

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et al. (2008) used an integrated approach by combining traditional and modern analytical techniques to characterize the different varieties of durum wheat and found that two-dimensional electrophoresis and determination of amylose content allow for the selection of suitable varieties for the production of pasta.

AbuHammad et al. (2012) examined the potential of different rheological methods for the evaluation of dough strength/gluten strength. They found that gluten index and quality indicators defined by alveograph are the best factors used to predict the quality of durum wheat pasta. In addition to the importance of the protein component for the quality of the final product, more recent studies have increasingly emphasized the importance of the starch component. According to the research that relies on the fractionation of individual components of semolina durum wheat and their reconstitution, Delcour et al. (2000) point out that in addition to gluten, there is evident importance of starch component and its properties, primarily the degree of crosslinking of starch on qualitative properties of the final product.

Increased competitiveness in the pasta making industry imposes new requirements with respect to the preliminary definition of durum wheat quality. In this sense, a great attention is placed on finding novel and more efficient methods of wheat quality assessment before its further processing. In recent years, a rheological instrument of a newer generation Mixolab has been largely used for a rapid assessment of the wheat *Triticum aestivum* quality (Codină et al., 2011; Vizitiu et al., 2012). As there is no sufficient data on its widespread usage in the process of durum wheat quality assessment, the aim of this work is to test its potential in the quality assessment of various durum wheat genotypes grown during two production years, to examine the relation between quality parameters, as well as to inspect the influence of climatic factors on the technological quality of durum wheat.

2. Materials and methods

2.1. Material

Genetic material used in this research includes 14 genotypes of durum wheat, both winter and facultative types obtained from the Gene Bank at the Maize Research Institute Zemun Polje, Belgrade, Serbia (Supplementary Table 1). Breeding lines of durum wheat have been grown on the same locality (Zemun Polje (ZP) (44°52′ N; 20°19′ E) and 88 m above sea level in Serbia during two production years (2012 and 2013).

Data on climatic conditions prevailing during the vegetation period from May to June in the experimental fields were obtained from the Republic Hydrometeorological Service of Serbia (RHSS). Average values for maximum temperature (mxt), minimum temperature (mnt), midrange temperature (mt), relative humidity (rh) and precipitation sum (pr) for May and June are shown in Table 1.

During the wheat vegetation period in May and June, which affects the quality and quantity of protein and starch in wheat grain, two production years differed in terms of duration of high temperature and precipitation sum. The period of 2012 was characterized by a longer heat stress in June, whereas 2013 production year had higher precipitation sum, for about 50% higher in May and more than twice higher in June.

2.2. Methods

The cleaned samples of wheat were soaked up to 16.5% humidity, conditioned for 24 h (AACC 26–31), and then milled on a Quadrumat Senior laboratory mill (Brabender, Duisburg, Germany). The yield of semolina is expressed relative to the total amount of durum wheat based on the moisture content of 16.5%. The determination of hectolitre mass, protein content, moisture content of durum wheat, moisture content of durum semolina was all carried out using the apparatus NIR (Infratec 1241 Grain Analyzer (Foss Analytical AB, Hillerod, Denmark)). Sodium dodecil sulphate (SDS) sedimentation of durum semolina, grain vitrousness and Falling number (FN) were determined according ICC standard methods 151, 129 and 107/1, respectively.

Table 1
Averages of climatic variables by months in 2012 and 2013 measured at the location Zemun Polje.

Month	Year 2012	Year 2013
Maximum temperature (°C)		
May	30.0	31.7
June	35.7	35.4
Temperature upper 30 °C (25 °C) (days)		
May	1 (11)	3 (15)
June	19 (26)	9 (16)
Minimum temperature (°C)		
May	6.9	6.2
June	8.1	9.3
Average mean temperature (°C)		
May	17.3	18.2
June	24.0	20.7
Average relative humidity (%)		
May	71	66
June	56	71
Precipitation sum (mm)		
May	75.4	98.6
June	15.8	39.2

2.2.1. Protocol for Mixolab

The rheological behavior of the dough obtained from durum semolina during kneading and heating was monitored by utilization of Mixolab (Chopin Technologies, France), with application of "Chopin+" protocol for ICC 173, (ICC Standards, 2011). The Mixolab curve indicators are (Supplementary Fig. 1): WA - water absorption (%); C1 – initial maximum consistence during mixing (Nm) used for determining the ability to absorb water; dough development time (min); mixing stability - elapsed time at which the torque produced is kept at 1.1 Nm (min); C2 – minimum value of torsion during mixing and initial heating (Nm). The Mixolab parameters which give information about starch behavior were: C3 – maximum value (peak) of torsion during heating stage (Nm); C4 – stability of hot starch paste; (C3–C4) - difference between maximum and minimum of torsion during heating stage (Nm); and (C5-C4) - the amount of retrogradation i.e. the difference between maximum torsion after cooling period at 50 °C (C5) and torsion at a point (C4), (Nm). In addition, the angles α, β and γ were defined as protein breakdown, gelatinization and cooking stability rate, respectively (Vizitiu et al., 2012).

2.2.2. Measurement of α-amylase activity

α-amylase activity (CUg−1) of semolina was measured using the Ceralpha method (Megazyme International, Wicklow, Ireland) for the measurement of plant and microbial alpha-amylases. At least three replicates were performed for each analysis.

2.2.3. Determining grain hardness

Instrumental measurement of texture (hardness) of durum wheat grain lines was performed using a Texture analyzer-a TA.XT.plus (Stable Micro System, U.K.). Hardness is measured by the force required to fracture (crack) a wheat grain, expressed in grams (g). Measurements were taken using anprobefor fracturing. The values of this parameter are expressed as the mean value for 15 measurements on one sample.

2.2.4. Microstructure analysis of semolina samples

The structure of durum semolina samples upon coating it with a layer of gold was analyzed by Scanning Electron Microscopy (SEM) (Joel, JSM-6460LV Scanning Electron Microscope (Japan)) under high vacuum at accelerating voltage of 25 kV. Before recording the micrographs, it was reviewed the numerous fields of view for each sample and those selected for discussion are considered to be representative. The obtained micrographs (up to 10 images for each sample) were taken at different magnifications: 500×, 1000× and 2000×.

2.2.5. Particle size analysis

The size distribution of isolated starch granules was measured using a laser light scattering (Mastersizer 2000, Malvern Instruments, UK) in wet-cell mode. Prior to analysis durum wheat flour samples were washed out by Glutomatic (PerkinElmer, Sweden) apparatus in order to separate starch from gluten. The obtained starch suspension was filtered through a sieve with a pore diameter of 63 μm and filtrate was then centrifuged at 3000 g for 10 min. The remaining starch pellet was again suspended in 10 ml of distilled water and centrifuged. In order to obtain pure starch, this step was repeated 4 times. The standard refractive indices used were 1.31 for water and 1.52 for starch. Previously re-suspended sample in distilled water was transferred into the particle size analyzer dispersion tank until the instrument read ∼40%obscuration, and the measure was then conducted. The volumes of the starch granules were calculated on the assumption that all granules were spherical in shape.

2.2.6. Statistical data processing

In order to illustrate the variability of a chosen sample set, descriptive statistics was performed. The Principal Component Analysis (PCA) was used for finding the relationship between determined properties of durum wheat semolina samples. Statistical methods were performed using the Statistica 12.0 software (Statsoft, Tulsa, OK).

3. Results and discussion

The obtained results of analyzing the most important physical and chemical quality parameters of the durum wheat genotype samples observed in this study showed that the average protein content was significantly higher in 2012 (Table 2). Although grain hardness was significantly higher in 2013, the semolina yield showed the opposite trend which is in disagreement with results reported by Faměra et al. (2004). Nevertheless, the reduced quantity of proteins cannot be considered to be the same as reduced quality, since SDS sedimentation and grain vitreousness values are practically identical for both years.

Protein and starch quality, measured using values of SDS sedimentation and Falling Number vary greatly among wheat genotypes for both years (based on CV (%), Table 2). Taghouti et al. (2010) examined the impact of the year, wheat genotype and their interactions against the value of the standard durum wheat quality parameters in the case of adequate climatic conditions during three production years and found that the effect of genotype was dominant for SDS sedimentation volumes, yellow pigment content and hectolitre mass, whereas the effect of climatic conditions was the most significant for vitreousness and protein content.

According to Subira et al. (2014) hectoliter mass and vitreousness were the most dependent on environmental effect in Mediterranean countries (rainfed conditions with high temperatures and water scarcity).

Table 2
Semolina properties of durum wheat genotypes in two production years (2012 and 2013).

	Average	Minimum	Maximum	CV (%)
2012				
Hectolitre mass (kg/hl)	82.83	79.30	84.90	1.55
Yield of semolina (%)	67.10	68.00	76.80	20.2
Protein content (% d.w.)	15.01	12.90	17.90	10.32
SDS sedimentation (ml)	21.79	15.00	30.00	19.92
Vitreousness (%)	92.57	80.00	98.00	5.62
Hardness (g)	13629.60	10645.99	16315.06	11.62
Falling number (s)	806	540	1143	23.38
2013				
Hectolitre mass (kg/hl)	80.58	77.85	82.30	1.63
Yield of semolina (%)	64.96	61.00	70.60	7.15
Protein content (% d.w.)	13.75	12.10	16.10	8.24
SDS sedimentation (ml)	20.57	15.00	28.00	18.47
Vitreousness (%)	92.43	83.00	98.00	4.56
Hardness (g)	14590.07	12788.64	17298.97	9.32
Falling number (s)	453	324	629	22.14

Our research demonstrated a significant positive correlation for the following quality parameters: protein content and grain vitreousness ($r = 0.749$, $p < 0.05$), which matches the results reported by Sieber et al. (2015), grain vitreousness and hardness ($r = 0.696$, $p < 0.05$), corresponding to the results described by Dexter et al. (1988) and Turnbull and Rahman (2002), hectolitre mass and semolina yield ($r = 0.531$, $p < 0.05$), which is contrary to the results reported by Aalami et al. (2007), as well as protein content and SDS sedimentation ($r = 0.487$, $p < 0.05$), consistent with findings described by AbuHammad et al. (2012), contrary to the results reported by Rharrabti et al. (2003) (results were not shown).

The greatest differences in the values of the examined parameters between two production years were present in Falling Number and amylolytic activity. As the Falling Number merely represents an indirect measure of amilolytic activities in grain, we can undoubt fully conclude that the most significant changes occurred in the carbohydrate complex of the grain.

The FN values were significantly higher in 2012, whereas the values in 2013 showed higher mutual consistency (Fig. 1a). The amylolytic activity of samples in 2013 was significantly higher ($p < 0.05$) compared to the samples from 2012 production year which is in accordance with the climatic conditions prevailing in the tested years. However, wide variation of amylolytic activity values was evident for samples from 2013 (Fig. 1b) as indicated by the coefficients of variation CV (36.46% for 2012 and 58.73% for 2013 production year). The correlation analysis performed for FN values and amylolytic activity showed different correlations as follows: $r = 0.15$ for 2012, $r = 0.76$ for 2013 and $r = 0.67$ for both years, $p < 0.05$). The lack of stronger correlations could be caused by differences in the used samples for applied methods. FN method was conducted on whole meal flour (contains germ and outer layers) while amylolytic activity was determined in semolina. In that way the tested samples had different amount of amylolytic enzymes. This indicates that FN it is no longer a realistic indirect parameter of the level of the grain amilolytic activity, but rather an indicator of the starch complex structure in terms of size and shape of starch granules.

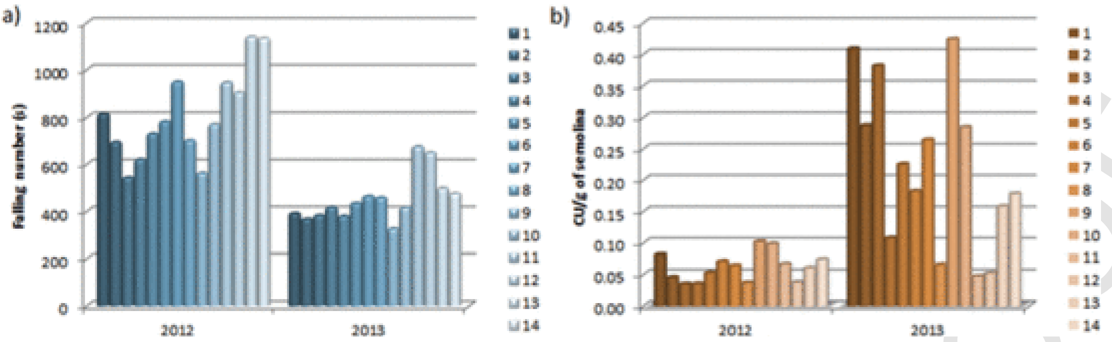

Fig. 1. Falling number values (a) and amylolytic activity (b) of semolina samples in two production years.

This is consistent with the claims reported by Thitisaksakul et al. (2012) that temperatures higher than 30 °C affect starch structure in wheat by increasing the content of amylose and short-chain amylopectin content, while the extent of changes in the structure depend on heat stress intensity and genotype heat-susceptibility.

Further confirmation of the established conclusions is evident in Mixolab curves whose appearances vary depending on the production year (Fig. 2a, b). Mixolab curves of the examined samples had a distinctive form for each year. In the initial part of the curve which characterizes the behavior of the semolina protein complex affected by thermomechanical changes, two groups of wheat varieties were differentiated in both years, based on the stability value and value C2. Nevertheless, the differences between the years in this part of the curves are virtually nonexistent. In contrast to the protein section of the curve, another section of Mixolab curves that describes the characteristics of starch-amylase complex patterns differ markedly between years (Fig. 2a, b). Generally speaking, 2012 samples are characterized by higher values of parameters C3, C4 and C5.

Based on these findings it can be assumed that the differences in the properties of the starch-amylase complex of durum wheat samples are the consequence of the different climatic conditions from anthesis to harvest (Table 1). Heat stress was a common feature for both years, but due to differences in the number of tropical days (Table 1), a different degree of shortening of the biosynthesis duration of proteins and starch might have happened as well. The second production year was characterized by significantly higher amount of rainfall, so that in synergy with a higher number of tropical days in May, it could be considered to be the cause of altered properties of the starch-amylase complex of durum wheat samples compared to the same wheat genotype grown in 2012. These variances are likely due to the differ-

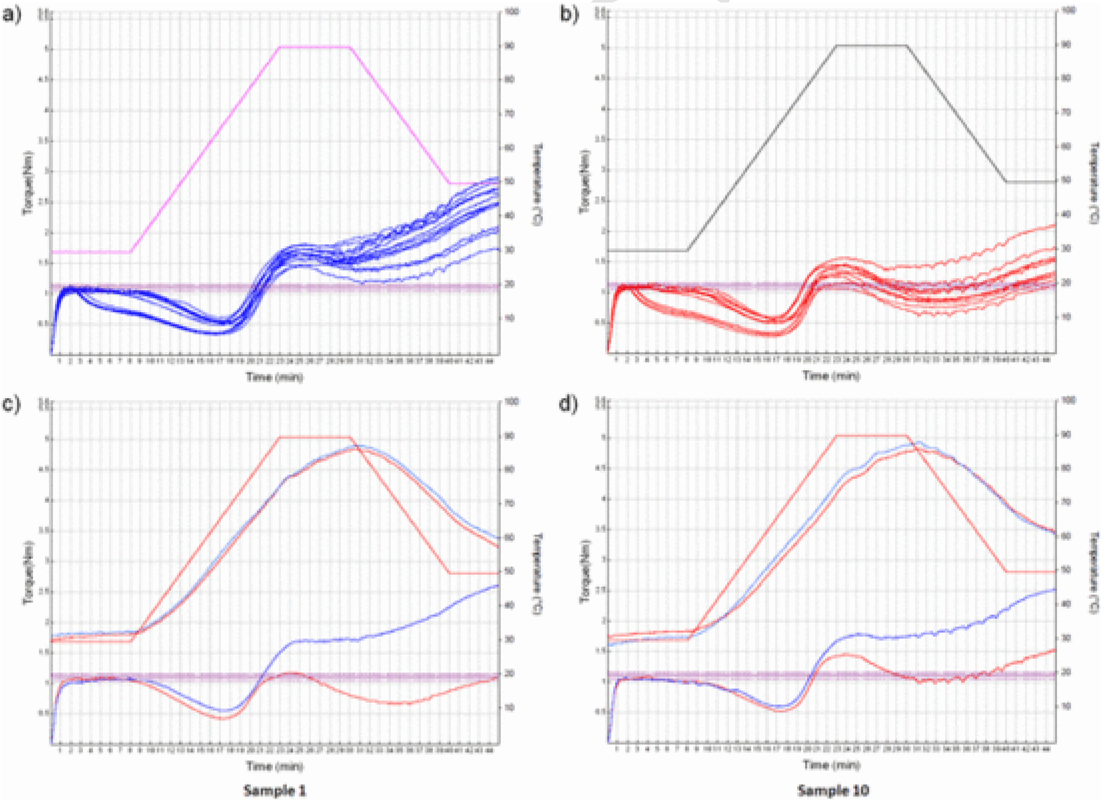

Fig. 2. Mixolab profiles of semolina samples in two production years: 2012 (a); 2013 (b) and comparison of Mixolab profiles of semolina from two durum wheat genotypes in two production years: sample 1 from years 2012 and 2013 (c); sample 10 from years 2012 and 2013 (d).

ence in the size of starch granules and their morphology (Falling Number and Mixolab), as well as ways of their formation in the endosperm, which had a direct influence on grain hardness, because there is no difference in grain vitreousness.

The maximum value of torsion in the heating phase (C3 Nm), was significantly higher in durum semolina samples from 2012, indicating a higher starch gelatinization temperature, i.e. higher viscosity of dough. The average value of the difference between maximum and minimum of torsion, in the phase of heating in the dough (C3–C4) is lower in 2012 (0.13) compared to 2013 (0.43) indicating lower amylolytic activity, and is consistent with the results of Falling number measurements in semolina suspension and amylolytic activity of semolina samples (Table 2, Fig. 1a,b). Stability of the hot paste in the test (C4) is lower in the semolina samples from 2013. In the like manner, higher values of C5 – a measure of retrogradation of starch molecules in the dough of semolina from 2012 are indicators of lower amilolytic activities of these samples (Vizitiu and Danciu, 2012). Increased resistance to retrogradation (lower values of C5–C4) is a distinctive characteristic of the dough samples of semolina originating from 2013.

Endosperm microstructure of durum wheat depends primarily on the duration of the grain filling stage including the weather conditions prevailing at the time. The optimum temperature for the longest duration of grain fill and the greatest accumulation of starch per grain is considered to be 15–20 °C (Dupont and Altenbah, 2003). Starch granules range from 1 to 60 μm and are classified into three main morphological groups: called A (10–35 μm), B (<5–10 μm) and C (<5 μm) granule types (Thitisaksakul et al., 2012). It is known that larger granules type A are first synthesized, smaller type B starch granules afterwards and much smaller type C granules are initiated late in development. It is believed that the occurrence of heat stress shortens the synthesis phase of type B granules thereby increasing the overall proportion of type A granules. Beside increase in number of type A starch granules, the heat stress affects formation of type A starch granules larger in size (Thitisaksakul et al., 2012).

On the other hand, there is no sufficient data in the published research so far on how each of starch granule fractions affects the values of Falling number and maximum viscosity on a milogram. According to Li et al. (2013), after starch fractionation, larger starch granule (A) showed a slightly lower viscosity than unfractionated starch, while the smaller starch granules (B) exhibited almost twice lower pasting viscosity. According to Lu et al. (2015), smaller starch granules cause low viscosity, whereas larger starch granules cause higher viscosity of wheat flour suspension. These data suggest that overall viscosity depends on the proportion of both starch fractions. Interpretation of the FN and C3 values in the tested samples in 2012 and 2013 leads to the conclusion that the starch component of all samples in 2013 contained much higher amounts of type B starch granules (lower viscosity) compared to samples of the same durum wheat genotypes originating from 2012 (higher viscosity). This is supported by data on the higher average value of water absorption for semolina in 2013 (63.8%) compared to 2012 (61.3%), since, according to Soh et al. (2006) and Sissons (2008) a greater content of type B granules increases the specific surface area to which it binds water. However, Liu et al. (2011) showed that the effect of heat stress from 6 to 8 days after anthesis was manifested by a smaller number of type A granules in comparison with type B starch granules and by type A granules with morphological deformations. This means that effects of high temperature during different grain-filling periods could lead to the even opposite consequences regarding the starch biosynthesis. If we consider that heat stress caused the increase of type B starch granules number, it could be an explanation of higher hardness values in samples from 2013 production year (Faměra et al., 2004). Beside that, the higher amylolytic activity of the same samples was additionally accelerated by tempering process before wheat milling. It deteriorated the endosperm structure thus decreasing the semolina yield (Miś and Grundas, 2002).

In order to better understand the differences in quality, samples 1 and 10 were selected for further analysis, on the basis of the same FN values for both years. They had different values of other examined parameters. Sample 1 in relation to the sample 10 is characterized by a greater dough stability for both years, and greater differences in the values of C2 (Fig. 2c, d). This indicates that there are some differences in the protein quality of the grain between samples originating from both years. What is common for both samples is the existence of differences between the two years illustrated in the part of the Mixolab curve from C3 to C5. Namely, in 2013 production year these samples had lower values of Mixolab parameters C3 and C4 and higher values of parameter C3–C4 which reflected the lower stability of hot starch paste and higher level of starch disintegration. It could be the consequence of determined higher amylolytic activity, starch granules morphology or both. For deeper interpretation of FN meaning, SEM micrographs and particle size distribution in selected samples were performed.

The micrographs (Fig. 3) of samples semolina 1 and 10 emphasize the compact structure of the endosperm sample 10 in both years compared to the sample semolina 1. Additionally, based on visual data in 2013, the small starch granules are more numerous in the sample semolina 10 in which higher values of torques C3, C4 and C5 were recorded by Mixolab, compared to semolina 1 sample. This was confirmed by particle size distribution results which showed that sample 10 from 2013 had higher amount of type B starch granules (11.39%) in comparison with sample 1 from the same production year (8.67%). Beside that as a common consequence of unfavourable climatic conditions, changes was happened in type C starch granules content ie. in increasing of their amount for 2% in average. Observed more compact structure of sample 10 in both production years was in accordance with results of grain hardness (14170.02 N in 2012 and 15075.73 g in 2013 in relation to 10852 g and 13560.07 g for sample 1). Furthermore, compared to 2012, both samples (1 and 10) from

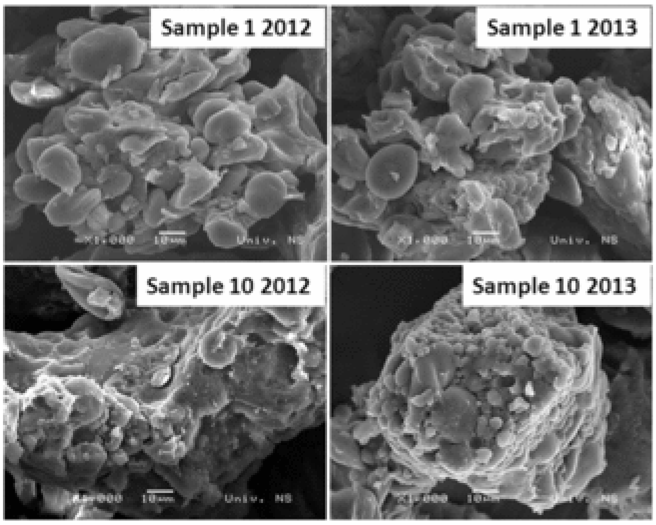

Fig. 3. Scanning electron micrographs of semolina from two durum wheat genotypes in two production years (sample 1 from 2012, 2013 (a, b); sample 10 from 2012, 2013 (c, d)).

2013 production year were characterized by higher value of grain hardness.

These results for sample 1 and 10 confirmed previous claim that FN value is not exclusively influenced by amylolytic activity but it is the consequence of the way of packing starch granules and their size.

3.1. Principal component analysis (PCA) of durum wheat quality data

The Principal Component Analysis (PCA) was used to observe the interrelation between analyzed variables and to find which properties are most important in distinguishing between investigated samples and properties.

The first two components of PC1 and PC2 explain up to 56.75% of the total variability of the basic set data of tested samples, and indicate significant correlations between the quality parameters of the starch-amylase complex (Fig. 4a).

The parameters most closely associated via vectors, which are significantly positively correlated, are the peak viscosity during pasting (C3), a minimum torsion after the heating period (C4), retrogradation (C5) and Falling number (FN). All indicators are negatively correlated with the gelatinization rate (β).

The second group of not so closely associated vectors, which are positively correlated with each other, are the hardness of grain (HARD) and vitreousness (VITR). The stability of the hot paste in the test (C3–C4) is in a positive correlation with water absorption (WA).

In the corresponding score plot there is clear distinction between genotypes from two production years. This indicates that the differences caused by climatic factors between the two years have uppermost influence in creating different quality of durum wheat breeding lines (Fig. 4b).

Since the first two components describe more than 50% of the total variability, and primarily account for the impact of starch-amylase grain complex on its properties, other parameters of quality in the further PCA analysis were excluded. The results show a loading plot (Fig. 4c) where the first two PC components explain even 93.99% of the total variability of the basic set of data of the examined samples of durum wheat semolina.

Sample distribution graph (Fig. 4d) indicates a more pronounced clustering of samples per production year compared to the previous score plot (Fig. 4b). These results suggest that the characteristics of starch-amylase grain complex were decisive for grouping wheat genotypes by production years. Additionally, this means that the climatic conditions in the two production years affected the differences in the quality of the starch part of the endosperm.

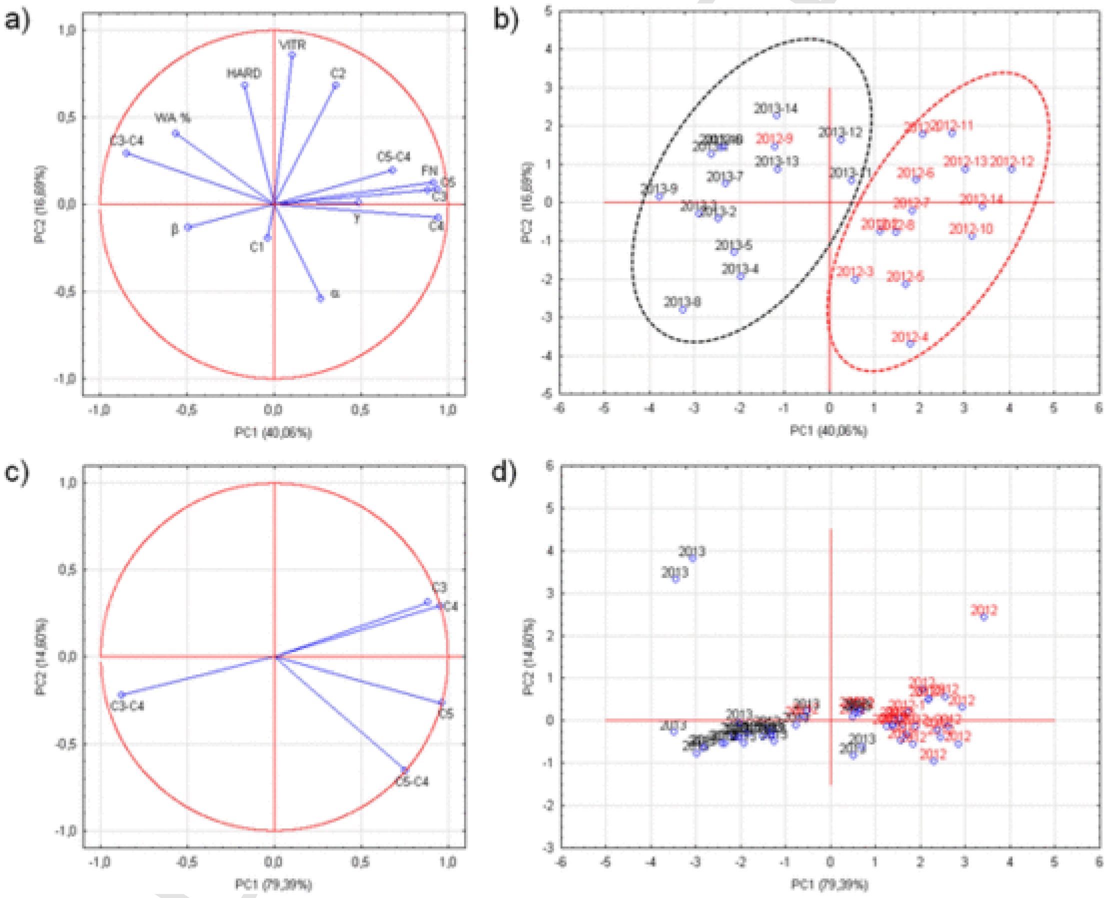

Fig. 4. Loading plot (a) and score plot (b) of the first and second principal components after PCA based on the selected data (Mixolab rheological characteristics, Falling Number, Vitreousness and Hardness); Loading plot (c) and score plot (d) of the first and second principal components after PCA based on the data obtained from Mixolab device related to the starch quality (C3, C4, C5, C3–C4, C5–C4).

4. Conclusions

In this work it was shown that the modern equipment Mixolab can be useful for a rapid characterization of different durum wheat genotypes.

Based on Mixolab curves, durum wheat genotypes originating from two production years with different climatic characteristics showed different technological quality. The stage of Mixolab curves showing the protein quality (C1 and C2) demonstrate the differences between the wheat genotypes, however, there are no differences with respect to the production year. On the other hand, stage of Mixolab curves which describe the characteristics of starch-amylase complex samples (C3, C4 and C5) differ significantly between two studied years. These results are in line with standard parameters of protein and starch quality of durum wheat (SDS sedimentation, Falling number), but they provide more complete information in a shorter time frame.

These results suggest the necessity of further research regarding the more detailed characterization of the carbohydrate complex of durum wheat examined samples, including the particles size distribution of the starch granules, the ratio of amylose/amylopectin, as well as properties of the enzyme complex of wheat grain.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jcs.2016.04.012.

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