Comparison of quality parameters of wheat varieties with different breeding origin under organic and low-input conventional conditions

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Abstract

The processing quality of 37 wheat varieties grown in Hungary and Austria (2011-2013) were assessed under organic and conventional low input management. The varieties studied were developed using three breeding strategies (conventional, organic and their combination: BFOA). The aim was to evaluate the effect of the field management and to assess the performance of varieties developed using different breeding methods, based on their quality traits under different managements. Furthermore, properties were identified that could characterize wheat quality and be used effectively for selection under both types of growing conditions.

Strong year and genotype effects were found for all the quality traits (protein, starch, gluten, GI, Zeleny, Farinograph water absorption, development time, stability and quality number, falling number, flour yield, hardness index) of the studied varieties, while the effect of the management was significant for the physical properties (test weight, thousand-kernel weight, hardness) and gluten quality characters (gluten spread, GI, dough stability) of the grain. The standard deviation of the gluten quality traits characterized the differences between the breeding

strategies. It proved possible to pre select organic varieties for quality traits with high broad-sense heritability under conventional growing conditions, but direct selection in organic fields is suggested for gluten quality characters.

Abbreviations:

BFOA   'Breeding For Organic Agriculture': method used for selection, involving conventional selection up to F5 and organic selection from the F6 generation

BLUE   Best Linear Unbiased Estimators

C   Country

CONV   Varieties bred conventionally in conventional fields

CV   Coefficient of Variation

E	Environment
G	Genotype
LI	Conventional low input field
M	Management
O	Organic field
ORG	Varieties bred in organic fields
REML	REstricted Maximum Likelihood algorithm: estimates variance parameters in linear mixed models
TKW	Thousand-Kernel Weight
TW	Test Weight
UPP%	Quantity of Unextractable Polymeric Protein as a %
Y	Year

1. Introduction

The necessity for separate organic breeding programmes is still a hot topic for wheat breeders, so there is a need to study the differences between the conventional and organic management systems (M), the effect of the environment (E), the effect of the genotype (G) and the properties of varieties developed using different breeding methods. Several research programmes have been established to obtain useful statements on the agronomical and technological properties of wheat varieties in this respect, but most of these compare high-input conventional and organic systems. Based on the results, a review by Lammerts et al. (2011) suggested that indirect selection would be effective for traits with high heritability (early maturity, plant height, thousand-kernel weight) under high-input conventional conditions, but this was not the case for quantitative traits (yield, end-use quality) influenced by GxE interactions, where direct selection under organic condition was suggested (Baenziger et al. 2011, Löschenberger et al. 2008, Muellner et al. 2014, Murphy et al. 2007, Przystalski et al. 2008). Differences in heritability estimates were identified for six traits (test weight, thousand-kernel weight, protein content, plant height, days to anthesis, spikes m $^{-2}$) under different management systems (conventional, organic) when Reid et al. (2009) studied 79 F_6-derived recombinant imbred lines. At the same time Annicchiarico et al. (2009) found higher broad-sense heritability for grain yield in high-input conventional systems than in organic.

GxE and GxM studies carried out earlier focused on the effects of the year, the weather conditions, the soil and/or the applied field management practices (fertilizers, manure, cultivation, plant protection, etc.) (Anderson et al. 1991, Baresel et al. 2008, Fliessbach et al. 2007, Foulkes et al.

1998, Gosling et al. 2006, etc.). However, these experiments mainly concentrated on the agronomical properties of the plants, and fewer results have been published from the viewpoint of the processing industry.

Previous studies showed that organic farming systems led to variations in the protein content and dough mixing stability of whole wheat flour (Gelinas et al. 2009). The protein content was found to be lower at the organic site, so varieties with high-quality protein and better nitrogen uptake were recommended for oganic farming purposes to compensate for the relatively low protein content of the grain (Osman et al. 2012). Significant GxE and GxM interactions were found for protein content by Kamran et al. (2014) when high-input conventional and organic systems were compared. Based on other studies, the gluten content, dough stability and loaf volume were higher under high-input conventional management (Annett et al. 2007, L-Baeckstrom et al. 2004, Krejcirova et al. 2007). Cultivars and farming systems (organic, high-input conventional) were found to have a significant effect on the yield and quality parameters (falling number, gluten content, gluten index, Zeleny) of organically and conventionally bred cultivars in the DOK long-term system comparison trial set up in Switzerland in 1978 (Hildermann et al. 2009). They found that the preceding crop (potato, maize) and the fertilization level had a significant effect on the protein content of wheat. Overall the conventional mixed farming system using half the standard fertilization rate performed the best, with higher grain yields and protein content (Mayer et al. 2015).

In contrast, Mäder et al. (2007) found no difference either in the protein content or in the amino acid composition, mineral content and baking quality of varieties grown under organic or high-input conventional farming systems. No differences were observed for the flavour, aroma or colour attributes of conventional and organic bread, but organic bread was denser in texture with smaller air cells in the crumb (Annett et al.

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2007, Kihlberg et al. 2006). In spite of these inconsistent results, wheat varieties suitable for organic cultivation and breeding have been selected, based on the gluten quality (unextractable polymeric protein content: UPP%) of 51 samples grown for eight years at organic sites in Sweden (Hussain et al. 2012).

Although some of the inconsistencies observed in the previous results may be due to the poor comparability of the field systems (different site, soil, crop rotation, etc.), they nevertheless underline the importance of further GxExM studies. Moreover, no wide-ranging studies have yet been performed on wheat varieties developed with different breeding methods and grown at low input and organic sites in different countries. Hence, in the framework of the EU-FP7 SOLIBAM project, the physical, compositional and end-use quality of 37 bread wheat varieties grown under different agro-climatic conditions in Hungary and Austria for three years were assessed using two different management systems (organic, conventional low input). The varieties were developed with three different breeding strategies: conventional, organic and a combination of these strategies, BFOA (breeding for organic agriculture). This experiment has already been evaluated from the agronomical point of view by Mikó et al. (2014), who found a significant MxG interaction for 15 traits and suggested that early selection should be made for heading date, sensitivity, leaf rust and powdery mildew under the conventional system, while grain yield, test weight, leaf-inclination and vigorous growth during booting should be used for selection in the target organic field.

The first aim in the present work was to evaluate the effect of the field management practices and to assess the effect of the breeding strategies on quality characteristics, followed by the identification of traits that could characterize wheat quality and be used effectively for selection under organic and low input conditions.

2. Materials and Methods

2.1. Plant material

Thirty-seven winter wheat varieties and breeding lines were sown at organic and conventional low input sites (henceforth 'low input') in two countries (Austria, Hungary) in 2011, 2012 and 2013. The varieties originated from 5 different countries (Austria, France, Germany, Hungary and Switzerland) and were bred in three different ways (Lammerts van Bueren et al., 2011). Nine varieties (Donnato, Aszita, Wiwa, Scaro, Butaro, Jularo, Sandomir, Gulliver, Karachow) were bred in certified organic fields, twenty (Mv Emese, Mv Béres, Mv Kolo, Mv Kolompos, Mv Tallér, Lukullus, Arnold, Capo, Midas, Claro, Lorenzo, Suretta, Titlis, Montdor, CH111-14426, CH111-14663, CH111-14631, Folklor, Renan, Flamenco) in conventional fields, and eight (Blasius, Peppino, Pireneo, Stefanus, Bitop, Tobias, Hendrix, Skerzzo) using a combined method (breeding for organic agriculture-BFOA), involving selection under conventional conditions in the early generations (usually up to F5) followed by selection in late generations on certified organic farms (Löschenberger et al. 2008). Detailed information on the origin and agronomical properties of the varieties were published by Mikó et al. (2014).

2.2. Plant growing conditions

The growing and management parameters of the trial locations and details of the environmental conditions were reported by Mikó et al. (2014). Between 2011 and 2013, 37 bread wheat varieties were sown in Austria (A) and Hungary (H) using a similar randomised complete block experimental design with 3 replicated blocks under organic (O) and low input (LI) growing conditions. In both countries the O and LI sites were located on neighbouring fields and the experiments were planted close to each other (<1080m) to minimize the confounding effects of differences in soil and climatic conditions. The low-input systems were characterised by a reduced level of mineral fertilizer, green manure, tillage and seed chemical treatment compared to high-input conventional farming systems. Furthermore, herbicides, insecticides and artificial fertilizers were used in the low input fields when necessary, but no fungicides. There was a serious *Tilletia caries* contamination at the organic sites in both countries in 2013, so fewer varieties and fewer quality parameters could be measured then. In the low input fields, nitrogen was supplied using mineral fertilizers according to local practice, while the organic crops only had the advantage of nutrients from the previous crops (mainly legumes) (Table 1 in Rakszegi et al. 2016). Weed pressure was very low at the organic sites in both countries in all the years. The weather conditions differed greatly not only between the years but also between the countries. After the moderately dry first season in 2010/2011, the year 2012 saw an extreme drought, which was followed by an average season in 2013. In most cases, the Hungarian locations received less precipitation and were warmer than the Austrian ones.

2.3. Assessment of quality traits

Physical properties

The test weight (kg/100 litres) of the grain was measured using a Foss Tecator 1241 instrument (MSZ 6367/4-86), while the thousand-kernel weight (TKW) was determined with a Marvin System according to the standard MSZ 6367/4-86 (1986) method. A Perten SKCS 4100 instrument was used to measure the hardness of the kernels (AACC Method 55-31).

Milling

After conditioning the grain to 15.5% moisture content, 700 g grain samples from each of the three field replications were milled separately using a Chopin CD1 Laboratory Mill to produce flour. Wholemeal samples were produced from the same samples with a Perten 3100 Laboratory Mill.

Grain composition

The crude protein content was analysed in duplicate with a Kjeltec 1035 Analyzer using the Kjeldahl method, which is consistent with ICC method 105/2. The gluten content and gluten index (GI) were determined using a Glutomatic 2200 instrument (ICC 137/1, 155). Gluten spread was measured according to the Hungarian standard MSZ 6369/5-87 (1987). This parameter provides information about the proteolytic activity of the samples by monitoring changes in the diameter of a gluten ball after 1 hour at room temperature. The starch content of the grain was measured with a Foss Tecator 1241 instrument. Basic grain compositional parameters were also estimated with the Near Infrared Spectroscopy (NIR) method (ICC 202 and ICC 159) using the Foss Tecator 1241 instrument for grain and the Perten Inframatic 8611 for flour.

Breadmaking quality characters

A Brabender Farinograph (ICC 115/1) was used to determine the flour water absorption, development time, stability and dough softening. The Zeleny sedimentation test was carried out according to standard ICC 116/1, while the falling number was measured using the Perten Falling Number System 1500 (AACC56-81B).

2.4. Statistical analysis

Linear Mixed Model analysis (using the restricted likelihood algorithm, REML) was carried out using SPSS 16.0 software (SPSS Inc., Chicago, IL, USA) based on Virk et al. (2009) with some modifications, as reported by Vida et al. (2014). A total of six sites (3 years × 2 countries) were regarded as different environments (E) and two different field management (M) systems (O and LI) were applied in all the environments for all the genotypes (G). In this model replication was the random factor. A second model was used for traits that showed a significant M × G interaction in the first model. The repeatability, genotypic variance, and variance of the G × E interaction were evaluated for each trait, for the two management systems separately. Repeatability (broad-sense heritability) was calculated as the ratio of genotypic to phenotypic variance. Linear Mixed Model analysis was also carried out to evaluate the effects of G, the year (Y) and the country (C) separately for both management systems (organic and low-input fields).

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Correlations between traits in the two management systems were determined on the basis of Pearson's correlation coefficient using the best linear unbiased estimators (BLUEs) of the traits generated by the mixed model (Evans 1996, Longin et al. 2013).

Discriminant Analysis was used to examine whether the 37 winter wheat genotypes in the two different management systems could be distinguished on the basis of their breeding origin. In this evaluation, average values of the traits assessed on the six sites (3 years × 2 countries) were used for each management system. More details of these methods were reported by Mikó et al. (2014).

Box and Whisker plots were prepared using the Statistica 6.0 software.

One-way ANOVA and Tukey's post hoc test were performed using SPSS 16.0 software (SPSS Inc., Chicago, IL, USA).

GGE biplot analysis was carried out using GenStat 17.0 software (VSN International Ltd., Hemel Hempstead, UK) (Yan and Tinker, 2006). GGE biplots illustrate the genotype plus genotype-by-environment variation using scores from principal component analysis, but without the environmental effects. The Ranking biplot (average-environment coordination (AEC) view of the GGE biplot) can be used to examine the performance of all the genotypes within a specific environment. In the plot, the best performing and most stable genotypes are those whose projections onto the biplot axis are closest to the environment. The single arrow on the AEC abscissa points to higher mean values of a given trait, while the distance from the AEC ordinate indicates to greater variability (poorer stability) in both directions. The "which-won-where" function of the GGE biplot is an extended use of the 'pair-wise comparison' function and shows which genotype performed the best in which environment. Genotypes located on the vertices of the polygon performed either the best or the poorest in one or more environment present in the same sector.

3. Results

3.1. Effect of G, E, C, Y and M on quality

Strong environmental (E=country x year) and genotype (G) effects were found for all the quality traits of the varieties examined (Table 1). Only the water absorption of the flour and the stability of the dough were affected less, but still significantly by the environment. The effect of the management system was less pronounced, mainly influencing the physical properties of the grain (test weight, thousand-kernel weight, kernel width) and parameters indicating the quality of the dough (gluten index, Farinograph dough development time, dough stability, quality number). The ExM interaction had a significant effect on all the traits assessed, except for dough stability. At the same time, the ExG interaction did not affect the grain composition (protein and starch content) or the dough properties (Farinograph development time, stability). The MxG interaction, which mostly demonstrates differences between the management systems (O, LI), significantly affected the thousand-kernel weight, gluten spread and gluten index. The interaction of the three factors (ExMxG) affected the physical properties of the seed (except test weight), the flour yield, and gluten quality parameters, such as gluten spread and gluten index. Grain yield was significantly affected by all the factors and by their interactions.

The genotypic variance and repeatability (broad-sense heritability) were calculated for each trait in the two management systems in order to discriminate the varieties in O and LI fields according to their quality. The heritability of all the quality traits was above 0.90 both at the LI and O

sites, but only those where the MxG interaction was significant are presented here (Table 2 in Rakszegi et al. 2016). The heritability of the grain yield was lower than that of the quality traits (0.85 and 0.70, respectively at O and LI sites), as explained in detail in Mikó et al. (2014).

The effects of the different environmental factors (country and year, C, Y) and the genotype (G) were also analysed separately at the organic and low input sites (Table 2) (except the Farinograph parameters, for which fewer data/replications were available). The effects of G and Y were significant for all the traits, while the influence of C was found to be smaller. Physical properties such as kernel width and hardness index were not affected by C at the LI site, while the effect of C was not significant for kernel width, flour yield or protein content at the O site. The Farinograph water absorption and dough stability were not affected by C either. The GxC and GxY interaction affected fewer physical properties at the O site than at the LI, but the most important quality parameters (protein and gluten content, Zeleny sedimentation, Farinograph parameters) were not affected by these interactions at either sites. The interaction between the environmental factors, CxY, had a significant effect on almost all the parameters, with the exception of falling number at the LI site and gluten content and index at the O site. The GxCxY interaction only affected the TKW, the kernel length, the hardness index and the gluten quality parameters (gluten spread, gluten index) at the O site, while only the grain composition (protein, gluten, starch content) and the breadmaking quality parameters (Farinograph, Zeleny) were unaffected by this interaction at the LI site.

3.2. Correlations between quality traits at the O and LI sites

Correlation coefficients between the best linear unbiased estimators (BLUEs) were calculated for 14 quality traits and were studied separately at the O and LI sites. The strength of the correlations was mostly similar for both management systems, though there were certain differences (Table 3). The relationship between the test weight and some of the other quality traits was stronger at the LI site (hardness index: r=0.22***, flour yield: r=-0.27***, Zeleny sedimentation: r=0.18**, water absorption: r=-0.23**), than at the O site (hardness index: r=0.13*, flour yield: r=-0.10, Zeleny sedimentation: r=-0.12, water absorption: r=-0.09). At the same time, the gluten content, gluten spread and gluten index seemed to be influenced by the test weight to a greater extent at the O site (r=-0.15**, -0.23***, 0.20***, respectively). The flour yield had a stronger correlation with TW, TKW, kernel width, water absorption, starch and gluten content and Zeleny sedimentation at the LI site (r=-0.27***, -0.15***, -0.23***, 0.31***, -0.22***, 0.18**, 0.18**). The diagonal of Table 3 represents the correlations between traits measured on the same samples at organic and low input sites. The lowest correlations between the O and LI sites were found for yield (r=0.59***), TKW (r=0.75***) and Zeleny sedimentation (r=0.77***). The grain yield showed similarly strong correlations with the quality traits at both the O and LI sites.

3.3. Discriminating variety groups bred using different methods

Discriminant analysis was carried out in order to study differences between the variety groups (bred using different methods) and the field management systems (O, LI) (Figure 1). Twenty quality traits were selected for the analysis, where Function 1 accounted for 62.1% of the total variance, with test weight (-0.24), thousand-kernel weight (-0.15) and kernel width (-0.18) having the greatest negative weight. Similarly, Function 2 accounted for 20.2% of the total variance, with gluten spread (-0.45), gluten and protein content (0.36 and 0.29, respectively) having

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the greatest positive effects, while gluten index (-0.41) had the greatest negative effect. These two Functions together therefore accounted for 82.3% of the cumulative variance, which increased to 92.7% when Function 3 (to which physical properties were again major contributors) was added. The quality of the organically bred varieties (groups 3 and 6) was significantly different from that of the conventional (groups 1 and 4) and BFOA (groups 2 and 5) varieties under both management systems (O, LI), which are clearly separated on the figure. The quality of the conventional and BFOA variety groups could not be distinguished, based on the 20 quality traits selected.

Additionally, the same 20 traits were evaluated separately using Box and Whisker plots to identify properties, capable of characterizing differences between the variety groups (organic, conventional and BFOA). In 2013 the organic sites were omitted from the analysis, as there was a serious *Tilletia caries* contamination in this year and not all the samples and traits could be measured. As a result it was found that the main determinant properties were related to the quality of the gluten, and thus to the quality of the dough (Figure 2). Only the results of the Austrian sites are presented here, as these were the most representative, but very similar results were found for the Hungarian site. The values of these traits (gluten index and gluten spread) were the most stable for the BFOA varieties in all the years and under both management conditions. At the same time, the standard deviation of the gluten index and spread was very high in the case of organically bred varieties. Thus, the difference between the organic varieties and the other varieties could be associated with the standard deviation of the gluten quality characters, rather than with the difference between the protein and gluten quantity or by the mean values of the gluten quality parameters.

3.4. Measurement of data variability and stability using the CV value

In order to measure the stability and variability of the quality traits, the coefficient of variation (CV) was calculated (Table 4), where lower values mean higher stability. A comparison of the CVs calculated for the organic and low input sites showed that the test weight and the falling number were more stable at the LI site than at the O site. At the same time, the Zeleny sedimentation, which is indicative of the expected bread volume, was more stable at the O site. The different variety groups were also compared and it was found that most of the properties, such as test weight, kernel length, kernel hardness, gluten spread, gluten index, dough development time, dough stability and water absorption, were the most stable for the BFOA varieties. The test weight of the conventional varieties was as stable as that of the BFOA varieties. Varieties where the most stably outstanding quality traits were achieved under organic conditions were identified based on the CV values and recommended for O or LI farming purposes (Table 5 in Rakszegi et al 2016).

3. 4. Mean performance and stability analysis of the genotypes using GGE biplots

The mean performance and stability of the genotypes across environments were evaluated using the ranking plot of the GGE biplot (Figure 1 in Rakszegi et al. 2016). Mv Emese had the highest mean TKW, followed by Mv Kolompos and Mv Béres, while Aszita had the lowest value. The TKW of Flamenco was the least stable, as it was lower than expected (end of arrow, biplot origin) at the AO site, but higher than expected at the HLI site. Mv Kolo was the most stable variety at the HLI site (variety closest to the HLI site on the figure), while Claro and Titlis were among the most stable varieties at the AO site. The varieties with the greatest stability at the ALI and HO sites were the most stable varieties of all, as they were closest to the end of the arrow (biplot origin) (for example Scaro, Capo, Gulliver, Lorenzo, Arnold, etc.). The biplot of kernel width

gave results similar to those for TKW, but both the varieties and the countries were better separated than the management systems. Varieties which were bred in Hungary had more stable kernel size at the Hungarian sites (Mv Kolo, Mv Kolompos, Mv Tallér, Mv Béres), while varieties bred in Austria or Switzerland were more stable in Austria (Bitop, Pireneo, Lukullus, Titlis, Claro).

The hardness of the kernel is important from the processing point of view. Aszita had the highest and most stable kernel hardness, while Gulliver had the softest kernels. The hardness of all the varieties ranged from 35 to 75 on a zero to 100 scale (Table 3 in Rakszegi et al. 2016). The protein and gluten content basically determine the breadmaking quality of the flour. Karachow had the highest protein and gluten content and Folklor the lowest. Mv Emese, Montdor and Tobias had higher protein content than expected (end of arrow) at the HLI site, while that of Aszita was lower than expected at the HLI site but higher than expected at the organic sites (AO, HO). Sandomir, Gulliver and CH111-14426 also had higher protein content at the O sites, while the gluten content of Sandomir was also high at the AO site. The breadmaking quality of the dough and the quality of the gluten were characterized by properties such as gluten index, Farinograph quality number, dough stability and Zeleny sedimentation. Although Karachow had the highest protein and gluten content, it had the lowest gluten quality parameters. In addition, Lorenzo had the the highest Farinograph quality number and Zeleny sedimentation, and Hendrix the best dough stability. Most of the varieties had gluten index values higher than 90 and the differences between the sites were small. The Farinograph quality number was able to distinguish the varieties at the different sites to the greatest extent. The varieties Arnold, Lukullus, Tobias and Folklor were the least stable for quality, with higher projection from the AEC abscissa and having Farinograph quality number higher than expected at the ALI site and lower at the HLI site. At the organic sites, varieties such as Butaro, Jularo, Donnato, Midas, Capo and Lorenzo were the best-performing genotypes in terms of the

Farinograph quality number. Based on dough stability, Montdor, Scaro and CH111-14631 performed the best at the HO site and Peppino, Pireneo and Blasius at the AO site. In the case of Zeleny sedimentation, the varieties performed differently in the different countries, but there was less distinct difference in the diverse management systems. Midas had the highest and most stable grain yield, while Karachow had the lowest. The grain yield of Tobias and Lukullus was unstable, as it was higher than expected at the ALI site and lower than expected at the HLI site (Figure 2 in Rakszegi et al. 2016).

3.5. 'Which-won-where' and mega-environment identification by GGE biplot

In the case of TKW, three environments (ALI, AO and HO) formed one mega-environment with Mv Emese on the vertices of the polygon, having the best performance with high TKW (Figure 3 and Table 3 in Rakszegi et al. 2016). The HLI site formed a separate mega-environment where the Montdor and Renan varieties performed the best. These four environments formed a single mega-environment in the case of hardness index, protein and gluten content, dough stability and Zeleny sedimentation, with Aszita, Karachow, Karachow, Hendrix and Lorenzo respectively, having the best performance for the different traits.

Although Karachow had the highest protein and gluten content, it had very poor gluten quality (GI, Zeleny, QN, stability). The Austrian and Hungarian growing sites formed two separate mega-environments for kernel width and Farinograph quality number. Bitop had the best performance for kernel width in Austria, while Montdor performed the best in Hungary. According to the Farinograph quality number, which characterizes the breadmaking quality of the dough, Arnold had the best performance in Austria and Montdor in Hungary. The organic and low-

input sites only belonged to different mega-environments in case of gluten index. For this trait, separate variety selection is necessary under different management systems and in different countries. Piereneo and Jularo performed the best in respect of GI at the HO site, and Hendrix at the LI sites. The four environments formed a single mega-environment in the case of grain yield, with Midas having the best performance (Figure 2 in Rakszegi et al. 2016).

4. Discussion

4.1. Limitations of the analysis

In this experiment, the quality traits of 37 wheat varieties were studied in three replications at O and LI sites in Austria and Hungary for three years. It should be noted, however, that the data analysis was complicated by a serious *Tilletia caries* contamination at the organic sites in both countries in 2013, so only the small number of less infected samples were analysed. All the 2013 samples were excluded from the analysis when making BoxPlots. In addition, Farinograph analysis was carried out on bulked flour samples from the three field replications in each year, which reduced the number of measurements by a third. The difference between the number of varieties in each breeding group (twenty were bred conventionally, nine in organic fields and eight using the BFOA method) made the dataset unbalanced and limited the possibilities of data evaluation.

4.2. Effect of the management system on quality

Based on the grand mean values, 3% higher test weight and 3.5% higher thousand-kernel weight was found at the LI site than at the O site (Table 4 in Rakszegi et al. 2016). In addition, properties such as kernel width, gluten index, dough stability and Farinograph quality number were also significantly higher for LI than for O. These properties also resulted in the separation of the O and LI sites on the discriminant analysis figure (Figure 1). At the same time, no difference was found either in the protein content or in the gluten content under the two management systems, similarly to the findings of Mäder et al. (2007), but differences were observed in the quality traits of the gluten and in their standard deviation. This result was not fully consistent with previous findings (Annett et al. 2007, Gelinas et al. 2009), but could provide an explanation of why the organic selection performed by Hussain et al. (2012) was effective on the basis of the gluten quality (UPP%). In contrast with the present findings, previous GxExM studies found significant GxE and GxM interactions for protein content (Kamran et al. 2014), but this may have been the result of the different systems to which the organic management system was compared (high-input or low-input conventional). However, GxE significantly affected almost all the other properties in the present study (Table 1).

Broad-sense heritability values were higher than 0.9 for all of the grain compositional and end-use quality traits and no difference was found between the organic and low input sites. Traits with high heritability were recommended by Lammerts et al. (2011) for indirect selection under high-input conventional conditions in the early generations of wheat breeding, while quantitative traits (yield, quality) influenced by GxE interactions were recommended for direct selection under organic conditions. In the present experiment all the traits had high broad-sense heritability, so in this sense, all the studied traits were suitable for preselection in a conventional system.

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4.3. Effect of breeding on the variation and performance of the varieties

Discriminant analysis separated the organic varieties from the conventional and BFOA genotypes at both the organic and LI sites (Figure 1). Properties characterizing the quality of the gluten were found to be key parameters when the different breeding strategies were compared. Organic varieties had higher average gluten content and gluten spread, but smaller gluten index than the conventional and BFOA varieties (Table 4 in Rakszegi et al. 2016). The best performing organic genotypes were Aszita for kernel hardness, Karachow for protein and gluten content and Butaro for breadmaking quality traits (Figure 3 in Rakszegi et al. 2016). On the other hand, these genotypes were worse performers for other quality traits. Organic varieties also had high standard deviations for these traits or even higher (Figure 2). This draws attention to the necessity of selection for gluten quality traits under organic conditions during wheat breeding.

Varieties with high quality protein and better nitrogen uptake were recommended for organic farming purposes by Osman et al. (2012), as lower protein content was typically found at the organic sites. In the present experiment varieties were identified with high-quality protein, such as Lorenzo, Hendrix, Butaro, Montdor and Stefano (Table 5 and Figure 1 in Rakszegi et al. 2016), which could be beneficial when growing them under organic conditions.

It is also important, however, to identify varieties that are less dependent on the environmental conditions, having stable quality traits at LI or O sites. Based on the BoxPlot analysis the BFOA varieties had the most stable gluten quality characters, but this may have been due to the fact that almost all the BFOA varieties were bred in Austria. Stability analysis showed that the kernel size and Farinograph quality parameters gave the best separation of the varieties on the GGE biplot, and making it easier to distinguish the varieties (Figure 1 in Rakszegi et al. 2016). All three

variety groups (CONV, ORG, BFOA) included stable and unstable varieties for one or more properties, indicating that preliminary decisions need to be made on selection traits, taking into consideration of the target end-use of wheat production. In the case of organic farming, this usually means the production of a specific local product with special quality requirements.

5. Conclusions

Although the quality of the studied varieties was found to be influenced by strong year and genotype effects, the effect of the management systems was also strong for some physical and gluten quality characters of the grain. The results also showed that the standard deviation of the gluten quality characters (gluten spread, gluten index, dough stability) could also be used to characterize differences between the breeding strategies, with BFOA varieties having the most stable gluten quality on both organic and low input farms according to CV and BoxPlot analysis. From the breeding point of view, high heritability values indicate that preselection could be made in a conventional system for all the traits, based on the needs of the processing industry. However, in order to achieve more stable processing quality characters on organic farms, selection is suggested for gluten quality characters under organic conditions.

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Figure captions

Figure 1. Combined groups plot (a) and classification results (b) of discriminant analysis based on the compositional and quality traits of 37 winter bread wheat varieties with three different breeding origins (CONV – conventional varieties, ORG – organic varieties, BFOA – BFOA varieties (varieties developed using a combination of breeding methods), O – organic site, LI – low input site, Austria and Hungary 2011-2013) where VG is the variety group and M is the management system.

Canonical Discriminant Functions

Function 2 (y-axis), Function 1 (x-axis)

VG_M
- ■ 1. CONV_LI
- ▼ 2. BFOA_LI
- ● 3. ORG_LI
- ■ 4. CONV_O
- ▼ 5. BFOA_O
- ● 6. ORG_O
- ■ Group Centroid
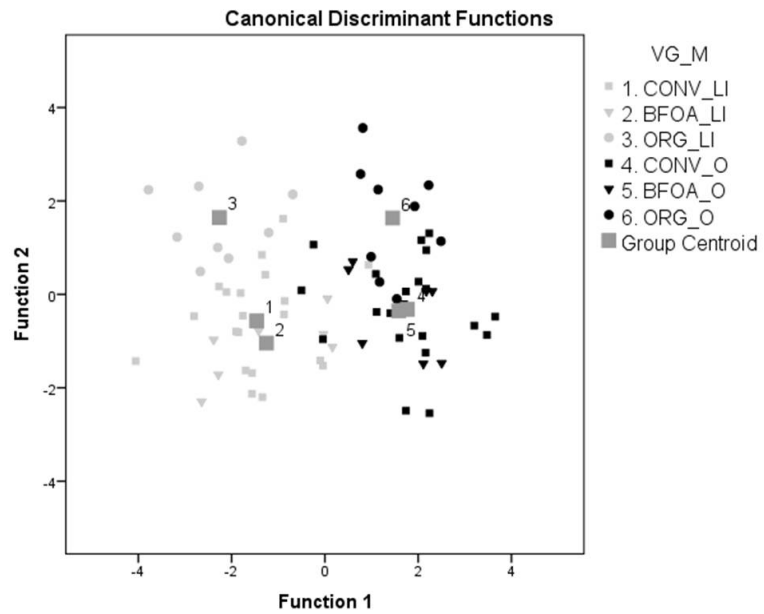
Classification Results[*]									
VG x Management			Group Membership						Total
			1	2	3	4	5	6	
Original	Count	1	13	5	2	0	0	1	21
		2	0	8	0	0	0	0	8
		3	1	0	8	0	0	0	9
		4	2	0	0	10	5	3	20
		5	0	0	0	1	7	0	8
		6	0	0	0	2	1	6	9
	%	1	61.9	23.8	9.5	0.0	0.0	4.8	100.0
		2	0.0	100.0	0.0	0.0	0.0	0.0	100.0
		3	11.1	0.0	88.9	0.0	0.0	0.0	100.0
		4	10.0	0.0	0.0	50.0	25.0	15.0	100.0
		5	0.0	0.0	0.0	12.5	87.5	0.0	100.0
		6	0.0	0.0	0.0	22.2	11.1	66.7	100.0

*69,3% of original grouped cases correctly classified.

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Figure 2. Box and Whisker plots of protein content, gluten content, gluten spread and gluten index at Austrian sites (CONV – conventional varieties, ORG – organic varieties, BFOA – varieties developed using a combination of breeding methods, O – organic site, LI – low input site, 2011–2013)
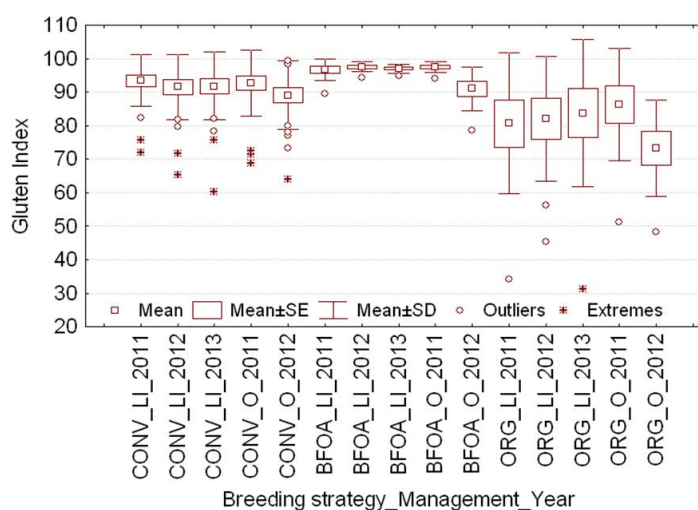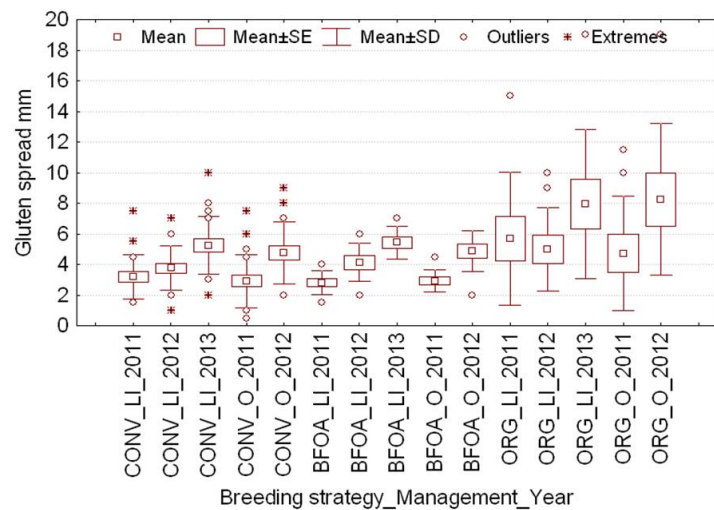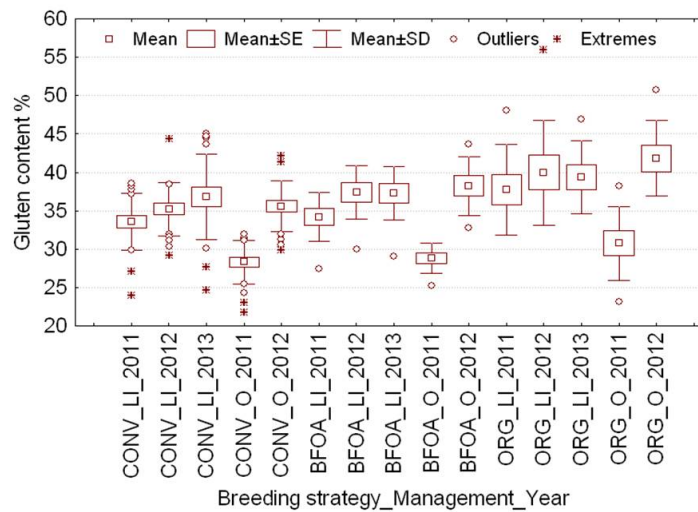
Table 1. Significance of the main effects (G, E, M) and their interactions for grain compositional and breadmaking quality traits tested using

Linear Mixed Model analysis (2011-2013, Austria and Hungary, organic and low input sites)

	G	E	M	ExM	ExG	MxG	ExMxG
Yield (t/ha)	***	***	***	***	***	***	***
Test weight (kg/hl)	***	***	***	***	*	n.s.	n.s.
Thousand-kernel weight (g)	***	***	***	***	***	***	***
Kernel Width (mm)	***	***	***	***	***	n.s.	***
Kernel Length (mm)	***	***	n.s.	***	***	n.s.	***
Hardness Index	***	***	*	**	***	n.s.	***
Falling number (s)	***	***	n.s.	***	***	n.s.	n.s.
Flour yield (%)	***	***	n.s.	***	***	n.s.	*
Protein wholemeal (Kjeldahl) (%)	***	***	n.s.	***	n.s.	n.s.	n.s.
Gluten content (%)	***	***	n.s.	***	***	n.s.	n.s.
Gluten spread (mm)	***	***	n.s.	***	***	*	*
Gluten Index	***	***	*	***	***	***	**
Starch (FOSS) (%)	***	***	***	***	n.s.	n.s.	n.s.
Zeleny sedimentation (ml)	***	***	n.s.	***	***	n.s.	n.s.
Farinograph water absorption (%)	***	*	n.s.	***	**	n.s.	
Dough development time (min)	*	***	*	**	n.s.	n.s.	
Dough stability (min)	***	*	***	n.s.	n.s.	n.s.	
Farinograph quality number	***	***	***	***	***	n.s.	

*,**,*** significant at the 0.05, 0.01, 0.001 probability levels, respectively
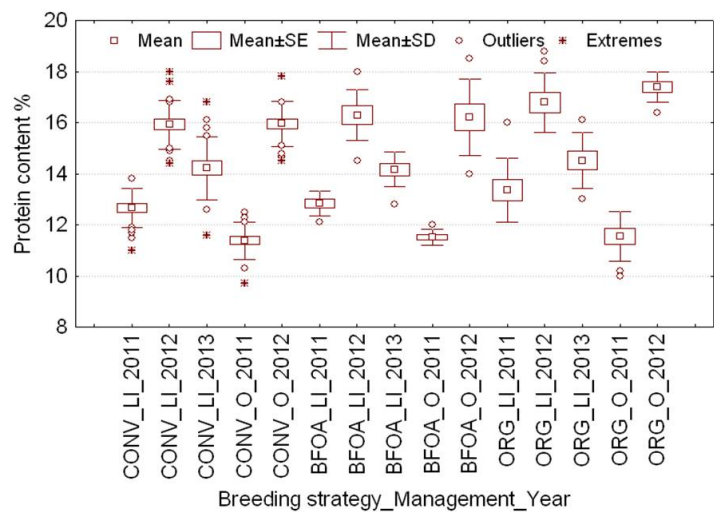
G-genotype, E-environment, M-management

Table 2. Significance of the main effects (G, C, Y) and their interactions for grain compositional and breadmaking quality traits tested using Linear Mixed Model analysis (2011-2013, Austria and Hungary, organic and low input sites)

	LI G	O G	LI C	O C	LI Y	O Y	LI GxC	O GxC	LI GxY	O GxY	LI CxY	O CxY	LI GxCxY	O GxCxY
Yield (kg/ha)	***	***	***	***	***	***	***	n.s.	***	***	***	***	***	***
Test weight (kg/hl)	***	***	***	***	***	***	***	n.s.	***	n.s.	***	***	***	n.s.
Thousand kernel weight (g)	***	***	***	*	***	***	***	**	***	**	***	***	***	***
Kernel Width (mm)	***	***	n.s.	n.s.	***	***	***	n.s.	***	*	***	***	**	n.s.
Kernel Length (mm)	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Hardness Index	***	***	n.s.	***	***	***	n.s.	n.s.	***	***	***	***	***	*
Falling number (s)	***	***	***	***	***	***	***	n.s.	***	n.s.	n.s.	***	**	n.s.
Flour yield (%)	***	***	***	n.s.	***	***	***	n.s.	***	**	***	***	***	n.s.
Protein wholemeal (Kjeldahl) (%)	***	***	***	n.s.	***	***	n.s.	n.s.	n.s.	n.s.	***	***	n.s.	n.s.
Gluten content (%)	***	***	***	***	***	***	n.s.	n.s.	n.s.	n.s.	***	n.s.	n.s.	n.s.
Gluten spread (mm)	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Gluten Index	***	***	*	**	***	***	***	**	***	***	***	n.s.	***	***
Starch (FOSS) (%)	***	***	**	**	***	***	n.s.	n.s.	n.s.	n.s.	***	***	n.s.	n.s.
Zeleny sedimentation (ml)	***	***	***	***	***	***	n.s.	n.s.	n.s.	n.s.	***	**	n.s.	n.s.
Farinograph water absorption (%)	***		n.s.		**		n.s.		n.s.		n.s.		n.s.	
Dough development time (min)	*		*		***		n.s.		n.s.		*		n.s.	
Dough stability (min)	***		n.s.		***		n.s.		n.s.		**		n.s.	
Farinograph quality number	***		*		***		n.s.		n.s.		***		n.s.	

*,**,*** significant at the 0.05, 0.01, 0.001 probability levels, respectively

G-genotype, C-country, Y-year, LI-low input, O-organic

Table 3. Correlation coefficients (r_P) between the best linear unbiased estimators (BLUEs) of 37 winter bread wheat varieties grown on low input fields (below diagonal) and organic fields (above diagonal, grey) and evaluated for physical, grain compositional and breadmaking quality traits (2011-2013, Austria and Hungary) Diagonal represents the correlation between the low input and organic sites (pale grey).

Traits	Yield	TW	TKW	KW	KL	HI	FN	FY	Protein	Gluten	GS	GI	Starch	Zeleny	WA
Yield	0.59***	0.23***	0.54***	0.51***	-0.04	-0.10	-0.78***	0,03	-0.79***	-0.78***	-0.55***	0.33***	0.64***	-0.65***	-0.90***
Test weight (kg/hl) (TW)	0.50***	0.85***	0.37***	0.29***	-0.37***	0.13*	-0.19***	-0.10	-0.29***	-0.15**	-0.23***	0.20***	0.29***	-0.12*	-0.09
Thousand-kernel weight (g) (TKW)	0.56***	0.38***	0.75***	0.87***	0.40***	-0.37***	-0.47***	0.12*	-0.40***	-0.37***	-0.35***	0.22***	0.35***	-0.28***	-0.45***
Kernel Width (mm) (KW)	0.64***	0.38***	0.77***	0.83***	0.13*	-0.26***	-0.36***	0.09	-0.30***	-0.29***	-0.39***	0.26***	0.24***	-0.17**	-0.39***
Kernel Length (mm) (KL)	0.07	-0.26***	0.47***	0.27***	0.92***	-0.58***	-0.02	0.28***	0.07	-0.06	0.10	-0.14*	-0.09	-0.08	0.00
Hardness Index (HI)	0.107	0.22***	-	-0.18**	-0.54***	0.88***	0.03	-0.72***	-0.09	0.09	0.05	0.05	0.14*	0.05	0.03
Falling number (s) (FN)	-0.46***	-0.43***	-	-0.42***	0.01	-0.03	0.84***	0.08	0.75***	0.56***	0.35***	-	-	0.58***	0.79***
Flour yield (%) (FY)	-0.32***	-0.27***	-	-0.23***	0.12*	-0.63***	0.33***	0.87***	0.19***	0.07	-0.07	0.00	-0.18**	0.12*	0.05
Protein content (%)	-0.71***	-0.30***	-	-0.47***	-0.05	-0.01	0.64***	0.30***	0.88***	0.84***	0.52***	-	-	0.87***	0.85***
Gluten content (%)	-0.52***	-0.05	-	-0.38***	-0.10*	0.12*	0.55***	0.18**	0.89***	0.83***	0.73***	-	-	0.84***	0.71***
Gluten spread (mm) (GS)	-0.33***	-0.05	-	-0.30***	0.06	0.03	0.22***	0.06	0.48***	0.64***	0.93***	-	-	0.49***	0.48***
Gluten Index (GI)	0.23***	0.15**	0.15**	0.25***	-0.11*	0.06	-0.22***	-0.08	-0.34***	-0.52***	-0.76***	0.96***	0.41***	-0.35***	-0.35***
Starch content (%)	0.62***	0.32***	0.42***	0.38***	-0.03	0.00	-0.64***	-0.22***	-0.94***	-0.85***	-0.41***	0.35***	0.83***	-0.75***	-0.77***
Zeleny sedimentation (ml)	-0.46***	0.18**	-	-0.30***	-0.16**	0.14**	0.55***	0.18**	0.89***	0.91***	0.53***	-	-	0.77***	0.74***
Water absorption (%) (WA)	-0.74***	-0.23***	-	-0.55***	-0.08	0.04	0.60***	0.31***	0.93***	0.83***	0.43***	-	-	0.82***	0.92***

*, **, *** significant at the 0.05, 0.01, 0.001 probability levels, respectively;

Table 4. Coefficient of variation (CV) for physical, grain compositional and breadmaking quality traits in different management systems (LI-low input, O-organic) and for different breeding methods (CONV-conventional, ORG-organic, BFOA- combination of methods)

| Traits | Coefficient of variation (CV) % | | | | | |
| | | Management | | | Variety group | |
	Total	LI	O	CONV	BFOA	ORG
Yield (t/ha)	31.67	35.70	26.05	32.23	30.46	30.29
Test weight (kg/hl)	7.72	**3.74**	10.62	**4.52**	**4.06**	13.56
Thousand kernel weight (g)	12.22	12.86	11.03	11.68	13.33	11.79
Kernel width (mm)	4.65	4.69	4.45	4.43	4.90	4.77
Kernel length (mm)	4.51	4.46	4.58	4.75	**2.94**	4.12
Kernel diameter (mm)	6.16	6.18	5.98	6.03	5.47	6.48
Hardness Index	15.49	15.58	15.36	15.31	**11.87**	18.11
Flour yield (%)	7.56	7.84	7.18	6.92	6.76	8.48
Falling Number (s)	26.77	**20.85**	31.87	27.37	24.87	27.09
Protein wholemeal (%)	18.83	19.91	17.42	18.62	18.54	19.21
Starch (%)	3.91	4.05	3.65	3.60	4.12	4.38
Gluten content (%)	20.75	22.28	18.77	20.31	19.58	20.86
Gluten spread (mm)	69.21	70.35	67.88	64.38	**48.27**	69.84
Gluten Index	14.85	14.82	14.88	12.34	**4.67**	22.59
Zeleny sedimentation (ml)	22.69	25.27	**19.22**	22.43	20.37	25.04
Farinograph water absorption (%)	5.40	5.13	5.90	5.06	**4.37**	6.70
Dough development time (min)	58.72	58.01	59.81	60.97	**48.51**	61.86
Dough stability (min)	42.66	41.45	45.23	43.72	**32.33**	48.93
Farinograph quality number	40.04	39.60	41.13	40.87	**33.74**	43.81

Bold indicates significantly higher stability