

# Relationship Between Grain Hardness and Malting Quality of Barley (*Hordeum vulgare* L.)

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## ABSTRACT

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In a three-year period, protein content, polysaccharides and values of the selected malting parameters were determined in 12 varieties of barley. Hardness was assessed using the particle size index (PSI) and a Do-Corder apparatus (BRA). Significant differences in the levels of hardness between the varieties were detected. Hardness was affected by variety from 37% (PSI) and 71% (BRA). Significant correlations were determined between the PSI and extract content (0.64\*\*\*), Kolbach index (0.66\*\*\*), friability (0.57\*\*\*),  $\beta$ -glucans in wort (–0.51\*\*\*) and colour of malt (0.57\*\*\*). Significant correlations were found between BRA and content of non-starch polysaccharides in caryopses (0.64\*\*\*), extract (–0.62\*\*\*), Kolbach index (–0.70\*\*\*), friability (–0.70\*\*\*),  $\beta$ -glucans in wort (0.79\*\*\*) and wort colour (–0.56\*\*\*). Correlation was determined between hardness and malting quality index (PSI 0.51\*\*\*, BRA –0.71\*\*\*).

**Key words:** Barley,  $\beta$ -glucans, Brabender, hardness, PSI, quality.

## INTRODUCTION

Physical and mechanical properties of a barley caryopsis and consequently of malt are a reflection of their chemical composition and internal structure. Hard grain can be defined as a grain resistant to penetration of foreign matter or resistant to destruction and breakdown to particles. On the contrary, soft grain can be defined as a grain that easily breaks down under pressure. Texture, i.e. the organization of individual grain components, first of all in endosperm, determines whether the grain will be hard or soft<sup>3,7,9,21,26</sup>. The texture is significantly affected by quantity, quality and the mutual ratio of proteins and starch. Nevertheless, size of cells and their mutual connections within individual tissues are no less important. Physical and mechanical characteristics of a hulled barley caryopsis and malt are most significantly affected by the characteristics of the endosperm and hulls. The terms mealiness and glassiness are used for the description of endosperm characteristics. Starch granules in a mealy en-

dosperm are packed loosely in a protein matrix. Glassy endosperm is characterized by more compact embedding of starch granules into a protein matrix and probably contains a larger amount of small starch granules<sup>25</sup>. In the caryopses with the mealy endosperm, the light after falling on the surface of the endosperm refracts in different directions and creates the image of a plump mealy surface. In the caryopses with a glassy endosperm, the light is refracted more or less in one direction and creates an image of glassiness. Subjective evaluation of mealiness and glassiness has been replaced by objective methods<sup>19,23</sup>.

The quality of the endosperm structure affects the water and enzyme distribution in the endosperm, a principal prerequisite for homogeneous modification of endosperm in the course of malting. Glassy endosperm is degraded more slowly than mealy endosperm<sup>9</sup> and thus the distribution and activity of key enzymes is affected and this leads to lower modification during malting. Therefore, the level of change is given not only by the endosperm properties, but also by the activity of the enzymatic apparatus of the caryopsis. It is possible that caryopses with harder endosperm and higher enzymatic activity will be modified comparably after malting to the varieties with a soft endosperm and low enzyme activity. Level of modification can be significantly affected by the application of gibberellic acid<sup>35</sup>.

Allison<sup>2</sup> found that the structure of the mealy endosperm with a very low milling energy, detected in the variety Triumph, was originally present in the old regional barley variety Kneifel (later Opavský) and proved that improvement of malting performance cannot simply be explained only by changes in the physical structure of the endosperm. This was also confirmed by the experiments of Taylor and Swanston<sup>39</sup> and Ellis et al.<sup>14</sup> who did not find a high correlation between milling energy and hot water extract.

Thomas et al.<sup>41</sup> suggested that both milling energy and hot water extract are influenced by genetic factors. Later studies on different populations revealed that the factor affecting milling energy and hot water extract was located on the chromosome 7(5H)<sup>40</sup>, but hot water extract was also affected by factors on chromosomes 2 (2H) and 3(3H).

The relationship of glassiness or mealiness and hardness is not completely explicit. With an excess of nitrogen in the soil and with maturation at higher temperatures, glassy grains can originate. Glassiness is thus caused more by outer conditions, while in contrast, hardness is established genetically<sup>28</sup>.

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**Table I.** Characteristics of tested varieties.

Varieties	Spring Winter	6/2 row	Malting quality index	Country of origin	Parentage
Vilna	W	2	2	NL	Intro//Cebeco 87262/Tamara
Luxor	W	6	2	CZ	LU 27/LU 16
Luran	W	6	2	CZ	LU 27/LU 16
Orthega	S	2	2	D	Ceb.7931/Pompadour//S.77323/Golf
Camera	W	2	2	GB	NRPB 87-5685c*Stamm 41
Nelly	W	6	3	D	Tapir/76079/3/Birgit/Banteng//Gerbel
Tiffany	W	2	4	D	Labea/Marinka
Heris	S	2	5	CZ	HE 4431/CE 431
Scarlett	S	2	6	D	Amazone/Breun St. 2730 e//Kym
Tolar	S	2	6	CZ	HE 4710/HWS 78267-83
Jersey	S	2	7	NL	Apex/Alexis
Prestige	S	2	7	GB	Cork/Chariot

MQI: 9 = the best quality; 1 = without malting quality.

Micromalting, the aim of which is to determine technological quality, is time demanding and expensive and it is not appropriate for situations where there is lack of time (barley purchase) or a lack of material (early phases of breeding programs). The aim of the following experiments was to acquire new knowledge about relationships between the malting quality of barley and selected physical characteristics of the caryopsis.

## MATERIALS AND METHODS

### Cultivars

Particle size index (PSI) and hardness on the Do-Corder apparatus were determined in twelve varieties of spring and winter barley<sup>29,30,32</sup> (Table I).

The seed samples were acquired from the testing stations of the Central Institute for Supervising and Testing in Agriculture of the Czech Republic, and were grown in the framework of the experiments for registration procedures. In each testing station, the varietal experiment was established in incomplete blocks, type alpha design with three replications. A mixed sample was formed from these three replications. Portions of sieving fractions over 2.5 mm were used for evaluation.

Monitoring lasted for three years (2001–2003). In each harvest year, the collections of varieties were grown in three testing stations. Collection of barley varieties (Table I) was the same for all testing stations and all harvest years. In total 108 samples were evaluated.

### Micromalting and analyses of malt

The micromalting test procedure followed the traditional method used in the Malting Institute of the RIBM in Brno and the trial malting method was the method accepted during the 102nd session of the EBC Barley and Malt Committee in Perugia, in May of 2000. Temperature of steeping and germination was 14.5°C, time of steeping and germination was 144 h. Temperature at the beginning of kilning was 50°C and 80°C at the end, time of kilning was 22 h. EBC methods<sup>12</sup> were used to assess the content of nitrogenous substances, starch,  $\beta$ -glucans and pentosans in the barley caryopses. Further, the ratio of large to small starch granules was determined using two different methods: Low Angle Laser Light Scattering (LALLS)<sup>6</sup>

and Gravitational Field-Flow Fractionation (GFFF)<sup>10,11</sup>. The malt samples produced were analyzed according to EBC<sup>12</sup> and MEBAK<sup>22</sup> methods. The malting quality index (MQI)<sup>31</sup> was used for the assessment of total malting quality. For the MQI calculation, the following parameters were used: content of nitrogenous substances (protein) in the barley grain, extract in malt dry matter, relative extract at 45°C, Kolbach index, diastatic power, apparent final attenuation, malt friability and  $\beta$ -glucan content in wort. In individual years, the samples from all three stations were micromalted in the same term, approximately 3 months after harvest. The results obtained from the analysis of non-malted barley grains and analyses of the malt were used for the statistical evaluations.

### Particle size index measurements

Relative hardness of barley was detected through determination of the particle size index (PSI – Particle size index for hardness) by milling the sample and sieving on a 0.075 mm sieve<sup>44</sup>. Twenty-three grams of grain was milled in a laboratory mill (LM 3303, Perten Instruments, Hamburg, GmbH) using head number two. Ten grams of the milled sample was taken and placed into the Sifter Swing 200 (Mezos, CR) and sieved at 180 [1\*min<sup>-1</sup>] for 10 min. The particles that fell through the sieve (throughs) were weighed. The particle size index (PSI) was calculated using the following equation:

$$\text{PSI} [\%] = (\text{throughs} [\text{g}]/\text{sample mass} [\text{g}]) \times 100$$

Lower PSI values mean harder endosperm<sup>1</sup> (in the text and tables, the results obtained by this method are marked with the abbreviation “PSI”).

Using this method, each sample was measured three times. The mean value from this measurement was used for statistical evaluation.

### Hardness according to Brabender

From each sample, three 50 g aliquots of barley grain were taken for measurement. Hardness was assessed on a Do-Corder apparatus (Brabender, New Jersey, USA). Grain grinding was recorded graphically and hardness was expressed by the peak area in cm<sup>2</sup> (in the text and tables, results obtained by this method are marked with the abbreviation “BRA”).

Each sample was measured by this method three times. The mean value from these measurements was used for statistical evaluation.

### Statistical analysis

The results were evaluated statistically using the analysis of variance (Table IIA, and IIB.), multiple testing (Table IIIA and IIIB.), correlation analysis and expressed by Pearson's parametrical and Spearman's nonparametrical method (Table IV) as the probability distribution of the studied parameters could not be regarded as the selection from normal distribution in all cases. The programs REML<sup>33</sup> and SPSS were used for calculations.

## RESULTS AND DISCUSSION

### Effect of variety, locality and year on barley caryopsis hardness

The relationship between the effect of variety and the effect of environment is important in terms of breeding. Variety, environment and their interactions affect the total levels of the studied parameters. Variety is one of the significant factors affecting barley grain hardness<sup>2</sup>.

Both methods that were used for the measurement of hardness determined that there were statistically significant differences between the varieties in the studied set. The effect of variety on variability of this parameter with the PSI method was nearly 38%. The results obtained with the Do-Corder apparatus were affected much more by variety and were around 72% (Table IIA and IIB). Similarly, Bertholdsson<sup>5</sup> determined the effect of variety on the value of grain milling energy at 65%.

The effect of variety on the level of hardness was marked and even prevailing. It suggests that the level of grain hardness can successfully be influenced in the framework of a breeding program.

Differences between the localities were highly statistically significant in both methods and this agrees with the results of Swanston et al.<sup>39</sup> The effect of locality on variability of this parameter with the PSI method was ca 29%, and with the Do-Corder apparatus was 5%. Bertholdsson<sup>5</sup> also showed a low effect of locality on hardness (12%). Statistically significant differences between the years were

**Table IIA.** Analysis of variance for grain hardness, measured by PSI.

Source of variation	d.f.	Mean square	Var. cp %	SE
Year	2	15.6 n. s.	2.4	0.6990
Locality	4	105.6***	29.3	4.1950
Variety	11	70.2***	37.9	3.3280
Residual	90	5.8	30.4	0.8580

**Table IIB.** Analysis of variance for grain hardness, measured by the Brabender method.

Source of variation	d.f.	Mean square	Var. cp %	SE
Year	2	17.1*	4.1	1.0180
Locality	4	18.3**	5.2	0.9630
Variety	11	142.8***	72.6	6.7660
Residual	90	3.9	18.1	0.5740

\*\*\* P = 0.001; \*\* P = 0.01; \* P = 0.05; n.s. nonsignificant.

found only with the results obtained with the Do-Corder apparatus. Swanston et al.<sup>38</sup> described different effects of locality and year on milling energy. The effect of year on variability of this parameter was in both cases small (2.4% and 4.1%, respectively).

Based on testing with the LSD method, the set was split into two different groups (Table IIIA and IIIB). Classification of the varieties in the groups was similar in both methods. These methods assigned Jersey, Prestige, Tolar, and Tiffany to the softer varieties. On the contrary, the varieties Luran, Vilna, Luxor, Camera, Orthege, and Nelly were assigned to the group with harder grains. The PSI method assigned the variety Scarlett to the softer varieties while the Do-Corder apparatus assigned it to the varieties with a harder grain. This suggests that the caryopses of this variety, and primarily the endosperm, were degraded in a similar way as the varieties with a soft grain. With the variety Heris the situation was different. The Do-Corder apparatus assigned this variety to the softer varieties, but the PSI method assigned it to the harder ones. Allison et al.<sup>34</sup> classified the varieties with different malting qualities using milling energy. Both of these methods clearly distinguished the varieties with limit values.

**Table IIIA.** Multiple range analysis for PSI (Method: 95% LSD).

Varieties	S/W	2/6	n	Average (%)
Jersey	S	2	9	20.63 a
Prestige	S	2	9	19.82 ab
Scarlett	S	2	9	19.36 ab
Tolar	S	2	9	19.17 ab
Tiffany	W	2	9	18.23 b
Orthege	S	2	9	15.47 c
Camera	W	2	9	15.22 c
Heris	S	2	9	14.99 c
Luxor	W	6	9	14.50 c
Vilna	W	2	9	14.12 cd
Nelly	W	6	9	14.00 cd
Luran	W	6	9	12.19 d

LSD(t) (P = 0.05) = 0.41.

Average values indicated by various letters are statistically different (P = 0.05).

S/W = spring or winter barley variety.

2/6 = 2 or 6 row barley variety.

**Table IIIB.** Multiple range analysis for Brabender. (Method: 95 LSD).

Varieties	S/W	2/6	n	Average (cm <sup>2</sup> )
Prestige	S	2	9	37.71 a
Heris	S	2	9	38.55ab
Tolar	S	2	9	39.92 bc
Jersey	S	2	9	41.31 c
Tiffany	W	2	9	41.56 c
Camera	W	2	9	44.65 d
Scarlett	S	2	9	44.75 d
Nelly	W	6	9	46.17 de
Luxor	W	6	9	46.43 def
Orthege	S	2	9	47.84 efg
Vilna	W	2	9	48.22 fg
Luran	W	6	9	49.61 g

LSD(t) (P = 0.05) = 1.84.

Average values indicated by various letters are statistically different (P = 0.05).

S/W = spring or winter barley variety.

2/6 = 2 or 6 row barley variety.

## Effect of the grain composition on hardness

The protein, starch and nonstarch polysaccharide ( $\beta$ -glucan and pentosan) content was determined in non-malted barley caryopses. At the same time, starch granule size distribution using two physically different methods (LALLS and GFFF) was studied.

The quantity and quality of the nitrogenous substances contained in the caryopsis significantly affect physical characteristics<sup>4,27,20</sup>. Research suggests that although glassiness is connected with high nitrogen content and meakiness with low nitrogen content<sup>8</sup>, glassy or mealy endosperm can have grains with similar nitrogen content<sup>16</sup>. The hordein proteins of mealy endosperm modify faster than the hordein proteins of glassy endosperm<sup>18</sup>.

The range in which the protein content in the individual samples of the followed set varied was considerable (7–14%). However, the effect of protein content on caryopsis hardness was not statistically significant. Despite a low correlation (Table IV), the trend shown suggests that with increasing content of nitrogenous substances, the hardness of the caryopsis increases. This has been observed by numerous authors<sup>4,15,42</sup>. Qualitative protein composition affects caryopsis hardness more significantly<sup>27</sup>. Slack et al.<sup>34</sup> suggested that the hordeins in the protein matrix are a main obstacle to starch granule degradation. Individual hordein groups exhibit different biochemical characteristics and different amino acid compositions and this is reflected in formation of chemical bonds and their stability. The hordein proteins of mealy endosperm modify faster than the hordein proteins of glassy endosperm<sup>23</sup>.

Some hordein proteins are more resistant to proteolytic modification<sup>22</sup> and can create clusters in the endosperm that have firmer bonds between the starch granules and the protein matrix and thus are more resistant to modification.

The starch content affected the level of caryopsis hardness in a statistically significant manner but the correlation was not strong (PSI 0.42\*\*\*, BRA –0.48\*\*\*) and it showed explicitly that caryopsis hardness declines with the increasing starch content. This corresponds with the results obtained by Henry and Cowe<sup>15</sup> and Tohno-oka et al.<sup>42</sup> Swanston<sup>36</sup> studied the effect of starch quality on the level of milling energy. Lines with a crumbly endosperm exhibited lower grain milling energy and the starch granules of these lines broke down more easily during milling.

In our set, the relationship between the ratio of large and small starch granules and caryopsis hardness was not statistically significant. This could be due to the small differences in the ratio of large and small starch granules in the varieties examined. Compactness of packing of the starch granules in the protein matrix, protein matrix composition and the total area of all starch granules in the endosperm all affect caryopsis hardness. Ellis et al.<sup>13</sup> found out that an increase in the amount of small starch granules was connected with an increase in grain milling energy.

The ratio of the small and large starch granules did not relate to the caryopsis hardness measured by the PSI method and the Do-Corder apparatus (Table IV). On the contrary, Ellis et al.<sup>13</sup> found that an increase in the number of small starch granules was connected with an increase

**Table IV.** Correlation coefficients between the two parameters of grain hardness and the parameters of grain and malt evaluated by two methods.

Parameters	Spearman method		Pearson method	
	PSI	BRA	PSI	BRA
<b>Grain</b>				
Protein content (N $\times$ 6.25)	-0.1506 NS	0.041 NS	-0.1596 NS	0.0858 NS
Starch	0.415***	-0.4767***	0.4152***	-0.4857***
Distribution of starch granule size (LALLS)	0.0512 NS	0.1822 NS	0.0255 NS	0.1439 NS
Distribution of starch granule size (GFFF)	-0.0176 NS	0.1729 NS	-0.0416 NS	0.155 NS
$\beta$ -Glucan	-0.1877 NS	0.48186***	-0.1826 NS	0.5287***
Pentosans	-0.2988**	0.516***	-0.2988**	0.516***
$\beta$ -Glucan and pentosans	-0.3166**	0.6373***	-0.3121**	0.5112***
<b>Malt and unhopped wort</b>				
Extract of malt congress mash	0.6405***	-0.6229***	0.6433***	-0.6279***
Saccharide extract	0.551***	-0.4834***	0.5383***	-0.5039***
Mash method according to Hartong and Kretschmer VZ 45°C	0.4709***	-0.6173***	0.5131***	-0.6148***
Kolbach index	0.6628***	-0.6992***	0.6979***	-0.6977***
Soluble nitrogen of malt, Kjeldahl method	0.4078***	-0.532***	0.413***	-0.4856***
Final attenuation of laboratory wort from malt	0.389***	-0.5446***	0.3969***	-0.5412***
Friability	0.5692***	-0.7031***	0.5572***	-0.7085***
High molecular weight beta-glucan content of malt, FIA	-0.5094***	0.7949***	-0.492***	0.7607***
Fine grind/coarse grind	-0.472***	0.6568***	-0.462***	0.6516***
Glassy corns	-0.5223***	0.4077***	-0.4412***	0.3461***
Homogeneity (by friabilimeter)	0.5803***	-0.7682***	0.4834***	-0.7508***
Partly unmodified grains	-0.503***	0.738***	-0.4247***	0.7137***
Homogeneity (Carlsberg)	0.5326***	-0.6393***	0.5091***	-0.6258***
Modification (Carlsberg)	0.3428***	-0.4852***	0.3138***	-0.4704***
Diastatic power	-0.0221 NS	-0.1674 NS	-0.0162 NS	-0.1175 NS
Saccharification time	-0.1298 NS	0.2732**	-0.1472 NS	0.2649**
Colour of malt, visual method	0.5743***	-0.5648***	0.6324***	-0.4916***
Haze of wort (90°)	-0.3246**	0.4667***	-0.3407**	0.4848***
Haze of wort (15°)	-0.2592**	0.3934***	-0.2943**	0.4468***
Appearance (clarity) of wort	-0.2808**	0.4949***	-0.2693**	0.479***
Malting quality index	0.5074***	-0.7109***	0.506***	-0.6521***

\*\*\* P = 0.001; \* P = 0.05; \*\* P = 0.01; NS nonsignificant.

in grain milling energy. Swanston<sup>36</sup> also found an effect of starch quality on the level of milling energy.

Mechanical characteristics of cell walls formed mainly by nonstarch polysaccharides, together with the mechanical characteristics of the cell content and level of packing among individual cells, affect the total physical characteristics of a caryopsis<sup>43</sup>. The levels of correlation between  $\beta$ -glucans and pentosans and caryopsis hardness were not evaluated equally by both methods (Table IV). The Do-Corder apparatus found more significant correlations in this relationship (0.48\*\*\*, 0.52\*\*\*), than the PSI method (-0.19NS, -0.30\*\*). However, both methods recorded the same trend, i.e. caryopsis hardness increased with the increasing content of nonstarch polysaccharides. With the content of nonstarch polysaccharides ( $\beta$ -glucans and pentosans) expressed together, the correlation achieved a level of 0.64\*\*\* on the Do-Corder apparatus and this corresponds with the results of numerous authors<sup>5,15,17,37,42</sup>.

The results achieved showed that the quantitative distribution of protein, starch and nonstarch polysaccharides in a barley caryopsis significantly affected hardness. Differences amongst samples caused by variety and the environment, suggest that to obtain more in depth knowledge of the relationships between caryopsis hardness and composition, it will be necessary to pay additional attention to the qualitative composition of these substances.

### Effect of the caryopsis hardness on the selected malting parameters

Malting parameters were not influenced by caryopsis hardness directly and the relationship was markedly affected by the malting process itself. During malting not only caryopsis physical properties, but also the activity of the enzymatic apparatus and the accessibility of high molecular substances to enzymatic degradation, play a role. Therefore a lower level of mutual relationship between caryopsis hardness and malting parameters could be expected.

Both the methods used for the measurement of hardness confirmed that starch modification was significantly affected by caryopsis hardness. Extract content (PSI 0.64\*\*\*, BRA -0.62\*\*\*), and saccharide extract<sup>29</sup> (PSI 0.55\*\*\*, BRA -0.48\*\*\*), declined with increasing caryopsis hardness and this corresponded to the correlations found by Home, Elamo<sup>17</sup> and Taylor, Swanston<sup>39</sup>. In contrast, a nonsignificant correlation between the level of hardness and extract content was determined by Ellis et al.<sup>14</sup> and Swanston et al.<sup>37</sup>

The relationship between barley caryopsis hardness and activity of starch-hydrolyzing amylolytic enzymes (mainly  $\beta$ -amylase and  $\alpha$ -amylase), expressed as diastatic power, was not statistically significant. The relationship between caryopsis hardness and the efficiency of the amylolytic enzymes expressed as saccharification time was also not statistically significant. The activity of the amylolytic enzymes was sufficient and was not affected by caryopsis hardness. However, caryopsis hardness negatively affected starch accessibility to enzymatic degradation.

Protein modification was also significantly affected by caryopsis hardness. With increasing caryopsis hardness, the amount of soluble nitrogen in wort (PSI 0.41\*\*\*, BRA -0.53\*\*\*), and at the same time the level of protein

modification expressed as the Kolbach index (PSI 0.66\*\*\*, BRA -0.70\*\*\*), declined. A similar relationship has been reported by Swanston et al.<sup>37</sup>

Relative extract at 45°C (i.e., extract increased by the activity of thermally stable enzymes such as proteases and  $\beta$ -glucanases), was also highly statistically significant as affected by caryopses hardness (PSI 0.47\*\*\*, BRA -0.62\*\*\*).

Increasing caryopses hardness reduced the level of proteolytic modification and thus probably also affected the value of wort colour. The value of wort colour declined with increasing caryopses hardness (PSI 0.57\*\*\*, BRA -0.57\*\*\*).

A significant correlation was determined between caryopsis hardness and cell wall modification. Both methods recorded the same trend (i.e., with the increasing caryopsis hardness, the modification of the cell wall deteriorated during malting). A highly significant relationship between caryopsis hardness and the value of  $\beta$ -glucan content in the wort (PSI -0.51\*\*\*, BRA 0.80\*\*) was observed and this has also been reported by Home and Elamo<sup>17</sup> and Bertholdsson<sup>5</sup>. Friability (PSI 0.57\*\*\*, BRA -0.70\*\*\*), and the parameters related to it i.e., homogeneity by friabilimeter, glassy grains, partly unmodified grains, fine grind/coarse grind, homogeneity and modification (by Carlsberg) were significantly affected by the hardness of the caryopsis. Malts poorly cytolytically modified usually provide worts with opalescence or turbidity and this has been confirmed in this study. With increasing caryopsis hardness, the opalescence values (PSI -0.28\*\*, BRA 0.49\*\*\*), and wort turbidity values (PSI -0.33\*\*, BRA 0.47\*\*\*), rose.

In addition to colour and wort clarity, a lower level of modification of starch, protein and cell walls also affected the wort qualitative composition. With increasing caryopses hardness, the wort qualitative composition deteriorated and thus the values of apparent final attenuation declined (PSI 0.39\*\*\*, BRA -0.55\*\*\*).

Grain milling energy provides less information on malt sample technological quality than malt milling energy, but it can advise regarding necessary changes of technology for malting certain barley lines. In breeding, grain milling energy is used as a screening method only for extreme physical characteristics as it cannot distinguish samples of average values<sup>39</sup>. The advantage may be in assigning this method to selection earlier than the methods for the determination of malt milling energy.

### Malting quality index (MQI)

In the samples of the varieties examined, a number of parameters with direct or indirect impact on the variety utilization in the malt house were determined. The Malting Quality Index can be used for the measurement of differences in quality between varieties. With increasing level of hardness of caryopses, the MQI value declined (PSI 0.51\*\*\*, BRA -0.71\*\*\*) (Table IV).

## CONCLUSIONS

The results presented offer the possibility to use grain hardness as a screening parameter for differentiation of barley varieties. Correlation of hardness with selected

technological parameters shows the possibility of practical application of both methods in a grain quality prediction system. The rate and relatively small quantity of sample enables use of these methods during the early phases of selection in a breeding programme. In addition, hardness assessment can be used as a predictor of quality during the purchase of barley and also in barley grain trading.

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