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INVESTIGATIONS OF RELATIONSHIPS AMONG THE AGRO-PHYSICAL FEATURES OF WHEAT (*Triticum aestivum*) KERNEL VARIETIES

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1. AIM OF THE RESEARCH

The fundamental aim of the PhD work were the investigation of the kernel geometric, morphologic kernel hardness, agro-physical characteristic of the wheat (*Triticum aestivum*) and the clearing the relationship among these parameters.

In order to fulfil this aim we have investigated the following:

- geometry of the wheat kernel and effect of their measure
- the role of the harvesting yield and site in case of same varieties, showing and analysing the effects of the factors individually and altogether
- bulk density and envelope density of the wheat bulk and 1000 kernel weight, looking for relationships among the parameters
- we have determined the specific surface energy consumption, needed for milling wheat with experimental grinder, as the grinding resistance value (kernel hardness)
- we have determined the quality factors affecting the kernel hardness and looking for relationships among them

2. MATERIAL AND METHODS

We used the varieties of the Szegedi Gabonatermesztési Kutató Kht. (Cereal Research NPC, Szeged) as samples. The wheat kernels derived from crop years of 1999-2002., and location of Táplánszentkereszt, Fülöpszállás, Zsombó and Szeged. In case of several properties we have involved samples from earlier crop years of 1994-1998 as well. The preparation of the representative samples collected from the sites carried out according to the chess-board pattern method after cleaning (dust and coarse contamination).

2.1 Determination of the geometric and morphologic characteristics of wheat kernels

We applied 100-100 parallel measurements for determining the 3 sizes (length, width, thickness) with digital calliper and then we evaluate their ratio among each other with statistic.

2.2 Determination of the mass, volume and different density parameters of wheat kernels

The thousand kernel weight of the samples was investigated in 2 parallel measurements. Taking out 500-500 kernel from the samples we determined the mass values with digital balance.

The measurements of the density were carried out with volume expelling principle. We applied petrol-alcohol mixture as measuring medium. The obtained results derived from two parallel measurements.

The true density was measured with gas pycnometer type QUANTACHROME using Helium. This characteristic was measured in samples deriving from crop years of 2001 and 2002. We carried out 3 parallel measurements pro samples.
The bulk density (mass of 100 litres) was measured (1 dm^3) by a test weight apparatus with 3 parallels pro samples.

2.3 Determination of the kernel hardness as structure properties

The measurement of kernel hardness (HI hardness index) was carried out with PERTEN type SKCS 4100 measuring instrument. It measures not only the HI value but the mass, size and moisture content of the kernels as well and then show the average values of 300 kernels. The measurements of the samples were carried out with 3-3 parallel.

We have elaborated a method for the measurement of grinding resistance (specific surface energy consumption) based on grinding and the determination of the resulted kernel size of. The grinding was carried out with a hammer mill type KD-161 with modified sieve structure. For improving the accuracy we carried out experiments with laboratory disc mill type PERTEN 3303 too. The sieving was carried out with standard sieve series. The power consumption of the grinder was registered with digital power measuring instrument. We determined the grinding resistance with the modified equation of Bölöni energy function applying two variables.

The figures were evaluated with STATISTICA (StatSoft, Inc) és STATGRAPHICS (Statistical Graphyics Corp.) program package. The applied procedures were the following: describing statistics, normality investigation (χ^2-test, Shapiro-Wilk test, simple regression, multivariate regression, ANOVA, principal component analysis.

3. EVALUATION OF THE MEASURING RESULTS

3.1 Results of the investigation of kernel geometry

According to our measurements there is no relationship between the length and width measures. Therefore the sizes are variables **independent from each other**. We could find a deterministic relationship with middle level significance. The kernel measures relate with other agro-physical properties.

The width measure can be considered as most characteristic measure of the wheat. We could experience strong significant relationship between the width and thousand kernel weight whose reasons are the thousand kernel weight shows the development of the wheat and its value deriving from the width measure.

The length measure of the wheat has a specific importance. On his own it had a weak or maximum middle level significance with other properties but we can use it in calculation with multivariable equation very well.

The size distributions and mass measurements directed our attention for the role of the measure of thickness. It is important for several points of view. In case of image analysis we use an image analysis in 2 dimensions in general neglecting the thickness measure on the contrary it is an important characteristic of the wheat.

Assuming the asymmetric ellipsoid model we determined the theoretic mass of the wheat and then we compared it the measured thousand kernel weight and we obtained a mild correlation (R^2=0,765). The reason of the difference is the following. As it known, the wheat kernel has a ventral crease, which is closed, building a cavity in the middle. We compared the mass values according to the hard and soft class wheat. The difference and correlation coefficients is about 10% (R^2=0,809) and about 17 % (R^2=0,815) for soft and hard wheat respectively. It showed that there is a difference in the depth of the crease between the hard and soft wheat.

Outgoing from this result we established a multivariable equation with which the thicknes measure can be estimated with high safety. Our hypothesis has been demonstrated, the kernel hardness affects the accuracy of the estimation significantly. The equations for the hard and soft wheat are the following:

For hard wheat varieties (HI $\geq$ 50):

$$\mathbf{Th = 2{,}927 - 0{,}206 * L + 0{,}029 * TKW\ (R^2{=}0{,}63)}$$

For soft wheat varieties (HI < 50):

$$\mathbf{Th = 2{,}588 - 0{,}166 * L + 0{,}031 * TKW\ (R^2{=}0{,}72)}$$

where Th: Thickness (mm)
TKW: Thousand kernel weight (g)
L: Length (mm)

3.2 Results of density and mass measurements

We determined the density of the varieties with three methods: bulk density according to test weight (TW) measurement, the enveloped density measured with the fluid expelling involving volume measured together with crease, the true density involving the inner volumes of capillaries and inclusions, measured with pycnometer (He).

According to the expectations the results of the measurements of the bulk density and the envelope density reflected the genetic properties of the varieties in lesser extent, and the breeding conditions (crop year or site) in larger extent. We could not find any accurate relationships between the HLT and flour quality in the frame of this work.

The bulk porosity (ε) calculated on the base of the TW and the envelop density show the volume fraction among the kernels. There is an inversely proportional relationship between the HLT and porosity.

The quality of the kernel structure influence the porosity calculated from TW. It can be demonstrated from the following equations.

For hard wheat (HI ≥ 50)

$$\boldsymbol{\varepsilon = 0{,}722838 - 0{,}00403237 \cdot TW \ (n=105,\ R^2=0{,}73,\ r= -0{,}850)}$$

For soft wheat (HI <50)

$$\boldsymbol{\varepsilon = 0{,}672659 - 0{,}00344793 \cdot TW \ (n=59,\ R^2=0{,}66,\ r= -0{,}811)}$$

Where ε: Porosity
TW: Test weight ($kg/100dm^3$)

The correlation coefficient is R^2= 0,73 and R^2= 0,66 for the hard and soft wheat respectively

The crop year affected and modified the porosities. The effect of the rains and temperature could be demonstrated beyond the crop year. Its value was significantly different in the draughty crop years of 2000 and 2002 from each other and from the other crop years. It could be not detected significant difference among the varieties relating to the porosity.

The true density measurement provided new scientific result. The investigation of two hard and two soft varieties deriving from two different crop years resulted that the measured values differed from each other not significantly.

According to the figures of the two years we obtained 1.219 g/cm^3 and 1.435 g/cm^3 for the years of 2001 and 2002 respectively. Taking into account the relative error of the measurement we can state the obtained average value (1.4285 g/cm^3) can be considered as true density with high probability.

The meteorological conditions of breeding, the crop year and the location influenced the true density values more markedly. We have not experienced significant difference among the varieties**.**

The thousand kernel weight mass (TKW) shows the development and ripeness state of the kernel. Its measure depends on two factors: on the size and on the inner structure of the kernel. The geometric investigations demonstrated the first factor and the second ones can be concluded from the kernel hardness measurements and true density values

3.3 Results of the kernel hardness measurements

The kernel structure of the wheat depends on the consistency of the inner part of the kernel. It have been cleared the biochemical background of the kernel hardness too. A protein called friabilin with 15 kDa molecular weight is responsible for the softening of the originally hard structure (in a paradox way for the softness).

Under kernel hardness we understand a resistance against a given force. There are several methods for measuring the hardness, they measure mostly measure the force and time needed for grinding or analyse the size distribution of the resulting meals.

The new measuring method developed by us based on the application of the BÖLÖNI energy function with two variables

$$\mathbf{e_f} = \frac{\mathbf{e_d}}{\mathbf{\Delta a_d}}$$

where: $\mathbf{e_f}$ specific superficial grinding energy requirement (10^{-3} mWh/cm^2)
$\mathbf{e_d}$: specific grinding energy consumption (kWh/t)
$\mathbf{\Delta a_d}$: specific surface increase (cm^2/g)

Notice: The units are given in smaller decimals which can be interpreted better.

We ground the wheat varieties with a hammer mill with special developed grinding space. The energy input on the grinding shaft can be held on relatively constant. We measured the power consumption of the mill and then we determined the average size and the specific surface of the grit. The grinding characteristic of the kernel and the energy needed for grinding determine together the specific superficial grinding energy consumption according to the equation.

On the base of the investigation of several samples with different properties and varieties we can state, that the specific superficial grinding energy consumption, as the grinding resistance, is a material characteristic relating to the kernel hardness. The value of the grinding resistance depends on the applied grinding equipment, on the conditions of the grinding. It is suitable for determination of dimensioned grinding resistance of wheat in case of fixed conditions.

The grinding resistance takes into account the energy needed for the grinding and the changing of the size distribution of the resulting flours. It gives a dimensional value physically too depending upon the grinding machine but it is characteristic for the given variety in this way. This material characteristic is suitable for classifying the varieties (samples) according to hardness. Figure 2 shows the average values of grinding resistance of different varieties.

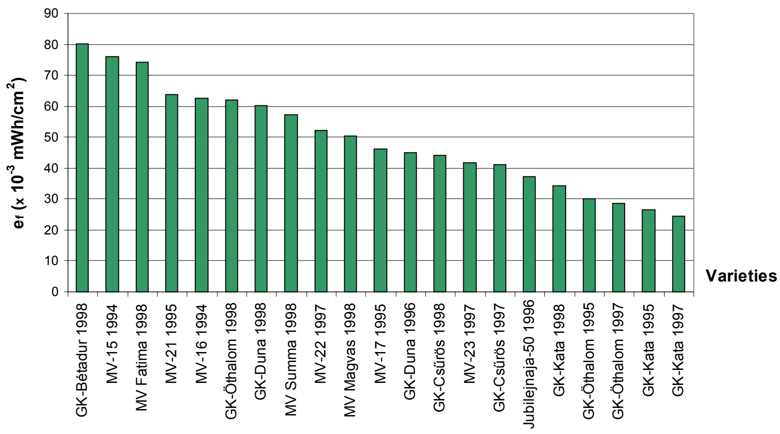


Figure 2 Average grinding resistance (e_f) of the investigated samples in descending order

Comparing it with the hardness index measured using Perten instrument type SKCS 4100 we could find a positive correlation with middle level significance (Figure 3).

$$\mathbf{HI = -1{,}953 + 1{,}064e_f \quad (n=21,\ r=0{,}66)}$$

Where:HI: hardness index (%)
e_f:: Grinding resistance (x 10^{-3} mWh/cm^2)

But it has to be mentioned, that the parameter covers not the same mechanical-physical properties. The kernel hardness and the grinding resistance cover similar structural property, but we have treated it as two separate variable. The kernel hardness means the mechanical resistance of the inner part of the cereal.

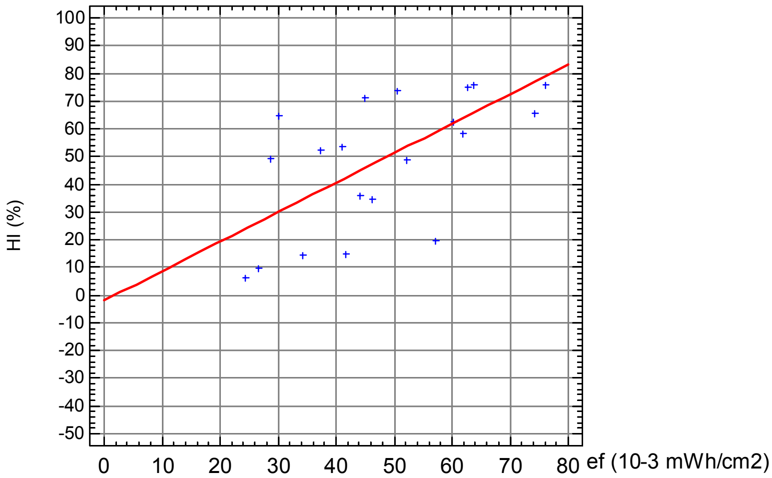


Figure 3 Relationship between grinding resistance and hardness index (n=21; r=0,679)

In order to decrease the auxiliary resistance and to increase the reliability of the measurement we carried out the grinding of 10 wheat varieties in a so called disc mill. The relationship between the grinding resistance measured with the disc mill and the hardness index became closer due to the ratio of the effective and loss energy (Figure 4). The mathematical form is the following.

$$\mathbf{HI = -19{,}996 + 1{,}88\ e_f\ (R^2=0{,}941,\ n=10,\ r=0{,}97)}$$

Where:HI: Hardness index (%)

e_f: Grinding resistance (x 10^{-3} mWh/cm^2)

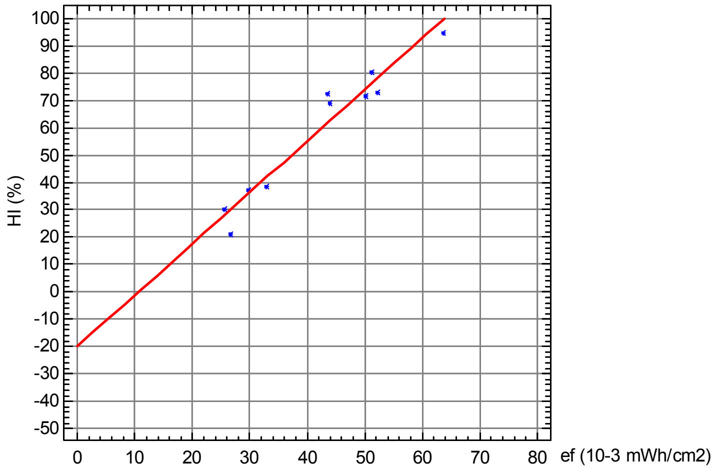


Figure 4 Relationship between the grinding resistance (e_f) measured with disc mill and hardness index (HI) for 10 wheat varieties

About the investigated three methods of the kernel hardness measurements we can state that the hardness inherited stably in the most varieties and they preserve the hardness rank in spite of the modifying effect of environment. There is a serious demand towards stable and homogenous hard wheat. We propose the investigation of the genetic background of the non stable varieties, excluding from the breeding.

We investigate the relationship between the kernel hardness and milling yield in the samples deriving from crop year of 2000. The 36 samples derived from different site. On the base of our investigation can be demonstrated that there is a positive correlation between the kernel hardness and the milling yield (Figure 5). The mild correlation demonstrates the advantage of the hard varieties and predicts the efficient grinding activity in the mill.

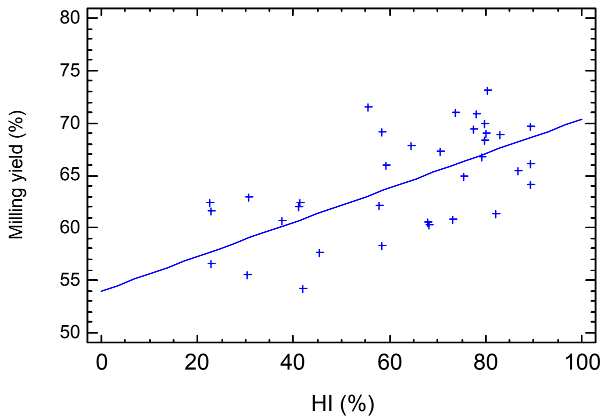


Figure 5 Relationship between kernel hardness and milling yield (n=36; r=0.63)

The estimation accuracy of the expectable milling yield can be increased. We demonstrated a significant and strong correlation between the estimated and measured milling yield with a linear equation based on the kernel hardness and measure of width. The mathematical form is the following:

$$\textbf{Milling yield} = 3{,}40979 + 15{,}8725 \cdot Wh + 0{,}174489 \cdot HI$$

(R^2=0,5424, n=36, r=0,734)

where Wh: width of the wheat kernels (mm)
HI: hardness index value of the a wheat samples (%)

The separability of the endosperm and bran can be correlated with the breaking characteristics of the kernel. The good separability relates with the breaking among cells (intercellular breaking). If the breaking lines pass through the endosperm cells more endosperm parts remained on the bran. The hardness of the kernel affects the way of the breaking significantly. The cells behave as a whole. It can be separated from the bran later on. In case of meal-wheat the cells has less rigidity, the shear forces split the cell and a part of the endosperm remained on the bran.

This is the reason for the less milling yield from soft wheat both in industrial and laboratory milling in spite of the smaller particle size of the grit.

We have investigated the relationship between the kernel hardness and water absorption in two crop years (2001 and 2002) (Figure 6). There was a positive and strong correlation between the two parameters in samples deriving from location of Szeged. We have to mention that we succeeded to demonstrate the relationship between the grinding resistance and water absorption capacity.

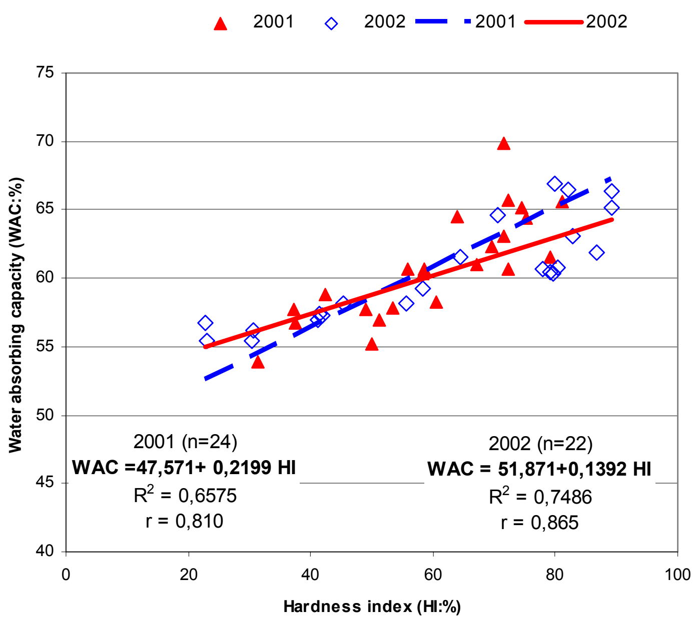
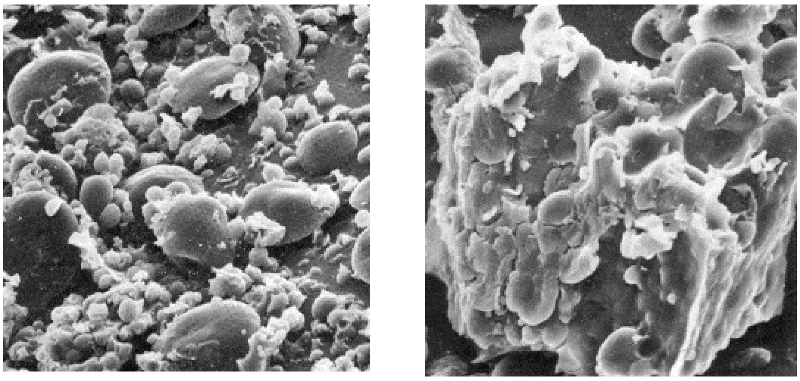


Figure 6 Relationship between kernel hardness (HI) and water absorption capacity (WAC) of wheat in samples of the years 2001 and 2002 (n=46)

We could conclude that the local characteristics of the site have a strong effect on the relationship between kernel hardness and water absorbing capacity. The deterministic and correlation coefficients proved this strong and significant relationship.



SOFT WHEAT **HARD WHEAT**

Figure 7 Picture of the flours deriving from wheat with different kernel structure (800x zoom)

On the left side and right side of the figure 7 we can see the microscopic pictures of the flours made from soft and hard wheat respectively (with courtesy of Henry Stevens).

The water absorption capacity can be related with the damage of the starch parts located in the endosperm. The starch particles of the hard wheat break meanwhile the starch turn out from the protein matrix in case of softer wheat.
The reason of the change of the water absorbing capacity is that the smaller grits deriving from the soft wheat are not able to transfer the water from their surface into their inner parts with a satisfactory speed. The water molecules slip on their surfaces in this way resulting dough with softer consistency. A harder dough structure can be established only by binding the added water into the inner parts or to the protein matrices quickly.

4. NEW SCIENTIFIC RESULTS

1. I establish an estimating equation between the particle size and thousand kernel weights taking into account the different kernel hardness. The estimation of the thickness can be carried out with an acceptable accuracy on the base of it.

2. I defined the term of the envelop density and demonstrated through experiments that the true density measured with pycnometer is a material characteristic affected less by the variety and more by the location.

3. I elaborated a new procedure for the measuring the hardness of kernel structure of wheat.

4. I determined the development of the specific grinding surface energy consumption on different wheat varieties. The hard and soft wheat kernels can be separated clearly on the base of it.

5. I demonstrated, that there is a mild-strong correlation between the Perten hardness index and specific surface grinding energy consumption measured with hammer mill as grinding resistance.

6. I stated that the relationship between hardness index and specific surface grinding energy consumption can be determined with disk mill more accurately.

7. I demonstrated that the kernel hardness of the wheat is a variety property fundamentally, which practically independent on the other agro-physical properties in case of same moisture content.

8. I demonstrated a clear correlation between the kernel hardness and milling yield obtained with laboratory mill. This is in good agreement with the miller’s experience.

9. I demonstrated that there is a definite positive and strong correlation between the wheat structure (hardness) and the water absorbing capacity of its flour. This can be due to the different form and particle size distribution of the flours deriving from wheat with different structure.

5. SCIENTIFIC PUBLICATIONS WRITTEN ABOUT THIS SUBJECT

Papers in scientific journals:

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4. Véha, A - **Gyimes, E** - Markovics, E. - Matuz, J.(2000): Relationship between the kernel-hardness and flour quality remarks by some different Hungarian wheat varieties Journal for Cereal and Flour Technology (Zito Hleb), Novi Sad Vol.27. No. 4-5. p126-134
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6. **Gyimes, E.** – Neményi Miklós - Véha, Antal (2002): Reológia és szemkeménység összefüggése őszi búzáknál In: Ötven éves az Acta Agronomica Hungarica Martonvásár, p.117-124
7. Véha, A. - **Gyimes, E.** (2003): Energetic Modelling of Wheat Kernel Hardness. Hungarian Agricultural Engeenering, Gödöllő Vol. 16. p. 66-67.

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VII. Növénynemesítési Tudományos Napok Budapest, 01.23-24. Abstract p.62.
2. **Gyimes, E.** – Neményi, M. (2002): Agrofizikai vizsgálatok a búza minőség megközelítésére MTA-AMB Kutatás-Fejlesztési Tanácskozás, Gödöllő január 15. Abstract, Nr.26 p. 43.

3. **Gyimes, E.** – Véha, Antal: (2002): A búza agrofizikai-, beltartalmi jellemzői és kapcsolatuk Tudomány Napja Szeged, 11.09.
4. **Gyimes, E**. – Neményi M. - Véha, A. (2003): A búzaminőség agrofizikai megközelítése. IX. Növénynemesítési Tudományos Napok Budapest, 03.05-06. Abstract: p. 51.
5. **Gyimes, E.** – Neményi M. - Véha, A. (2004): Az őszi búzák néhány agrofizikai jellemző és kapcsolatuk a szemkeménységgel. MTA-AMB 28. Kutatás-Fejlesztési Tanácskozás, Gödöllő január 20-21. Abstract, Nr.28 p. 54-55.
6. **Gyimes, E.** – Véha, A. (2004): A szemkeménység stabilitása valamint szerepe őszi búzák agrofizikai jellemzőinek becslésére. X. Növénynemesítési Tudományos Napok, Budapest, 02.18-19. Abstract: p. 53.

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2. **Gyimes, E.** – Neményi, M. - Véha, Antal (2002): Agrophysical features and stability of wheats ICC Conference, Budapest 05.26-29. Proceedings: 120-125
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2. **Gyimes, E.** (1999): Összefüggés-vizsgálatok a szemkeménység és néhány beltartalmi mutató között étkezési búzáknál V. Ifjúsági Tudományos Fórum Keszthely, 03.11 Proceeding p 153-157.
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