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INFLUENCE OF HARVEST DAY ON CHANGES IN MECHANICAL PROPERTIES OF GRAPE BERRIES

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ABSTRACT
Changes in the composition, physical and mechanical properties occur in grape berries during the ripening process, but the heterogeneity of the grapes harvested at different ripening stages affects the reliability of the results obtained. The characterization of the mechanical properties of grape berries seems to be an important parameter for understanding grape ripening. In this work, these changes were studied in seven grapevine varieties (*Riesling, Blaufränkisch, Pinot Noir, Cerason, Malverina, Laurot,* and *Hibernal*) harvested during six consecutive weeks. Mechanical behaviour was measured using compression and puncture tests using of TIRATEST 27025 testing machine. Skin mechanical properties were evaluated using a puncture test carried out on the equatorial side. The dependence of these properties on the chemical composition has been evaluated. These parameters of force/time curves were studied by puncture test: the berry skin break force, the needle displacement at the skin break and the berry skin break energy. The crushing force, the plate displacement at the crushing strength and the berry crushing energy were studied from force/time curves by compression test. Results of the puncture test shows that there the skin break strength and the acidity content are monotonic functions of the time. A comparison of different varieties from the point of the value of the crushing force was obtained by vertical and transversal loading. The crushing force is monotonically decreasing function of the harvesting time like the break force evaluated at the puncture test. The correlation between the skin break strength and the sugar content is significant namely for the varieties: *Hibernal, Riesling, Malverina*, and *Cerason*.

Keywords: grapes; acidity; sugars; texture; rupture

INTRODUCTION
Wine grapes undergo numerous physiological and biochemical changes during ripening inducing colour and texture changes **(Ribereau-Gayon et al., 2006; Coombe and McCarthy, 2000; Letaief et al., 2013; Le Moigne, 2008)**. During ripening, changes in the composition and structure of the cell wall as well as in the structure of the tissue, may determine the mechanical resistance and the texture of the fruit **(Abbott, 2004; Brummell et al., 2004; Hertog et al., 2004; Brummell et al., 2006; Deytieux-Belleau et al., 2008; Rolle et al., 2011)**. Grapes with low level of mechanical properties and damaged may be contaminated by fungi (e.g. *Penicillium expansum*) **(Tančinová et al., 2016)**. From this point of view the characterization of the mechanical properties of grape berries seems to be an important parameter for understanding grape ripening **(Doumouya et al., 2014; Carbajal-Ida et al., 2016; Fava et al., 2011)**. Previous studies applied the puncture test to characterize and compare the crunch texture of different table grapes **(Sato et al., 1997; Sato and Yamada, 2003)** and to follow the ripening process of white wine grapes such as Chardonnay and Riesling **(Lee and Bourne, 1980)**. These last authors showed that the mechanical properties of grape skin evolved during ripening and were significantly correlated with the °Brix for most grapes. Further work showed differences in mechanical properties of red wine grape varieties at a chosen harvest maturity level **(Letaief et al., 2008)** and differences in grape skin hardness **(Río Segade et al., 2008)**. However, there is no published work addressing the assessment of a mechanical method designed to monitor wine grapes ripening.

Preliminary research on the grape texture change showed that compression measurements were able to recognize veraison (a marker stage of berry development) earlier than a visual identification performed in the field, which is of particular importance for white grapes for which the colour change is slight **(Robin et al., 1997; Grotte et al., 2001)**. **Bernstein and Lustig (1985)** measured grape firmness and showed the relationship between turgor pressure and firmness. **Zouid et al., (2013)** show that the instrumental texture analysis can be very useful for to study the impact of the grapes heterogeneity according to sugar level on the physical and mechanical properties of *Cabernet Franc* grapes and to select the best instrumental parameters of the whole berries or of the skin linked with anthocyanins extractability. The next information on the instrumental texture analysis is presented by **Rolle et al., (2012)**.

The aim of this study was to define the best conditions to describe grape texture during ripening in order to obtain additional parameters that could be of benefit to ascertain the quality of ripening grape berries, in addition to the physiological parameters commonly used such as the acidity and sugar content.

MATERIAL AND METHODOLOGY

All grapevine varieties under study were grown in the experimental vineyard of the aforementioned faculty. This vineyard is situated in the vineyard site called "V Mendeleu" (In Mendeleum) in the wine village Lednice (region South Moravia, Czech Republic). The spacing of plants was 2.2 x 1.0 m and the plants were trained using Guyot pruning with 10 eyes per vine. This vineyard was established in 1993 and all varieties were grafted on the rootstock 5C.

Within the framework of this study altogether 3 cultivars of *Vitis vinifera* L. – *Riesling, Blaufränkisch* and *Pinot Noir* were evaluated together with 4 interspecific varieties: *Cerason*, *Malverina*, *Laurot*, and *Hibernal*. These varieties are maintained and evaluated within the framework of a collection of genetic resources of grapevine. Berries were sampled using the method described by **Iland et al., (2004)**.

Berries were randomly picked once per week, during the maturation period (from September to October in 2015). For compression test has been chosen six different dates: September 4 (week 1), September 13 (week 2), September 22 (week 3), September 30 (week 4), October 7 (week 5), and October 13 (week 6). For puncture test has been chosen the same dates without September 4 (week 1).

Each day of the harvest the following parameters were evaluated total acids in grapes. Total acid was calculated as all acids determined by HPLC method and expressed as tartaric acid. Total sugar was the sum of glucose and fructose **(Katalinic et al., 2013)**. The detail description of this method of analysis is described in **Pavloušek and Kumšta (2011)** briefly.

Mechanical behaviour was measured using compression and puncture tests. These tests were performed using of TIRATEST 27025 (TIRA Maschinenbau GmbH, Germany) testing machine. Skin mechanical properties were evaluated using a puncture test carried out on the equatorial side. Tests were performed with a cylindrical needle probe of 0.56 mm in diameter at speed test of 10 $mm \cdot s^{-1}$. Force/time curves were analyzed and three parameters were studied: the berry skin break force F_{sk} in Newton, the needle displacement p_{sk} [mm]at the skin break and the berry skin break energy W_{sk} [J = N·mm], see Eq. (1). These tests have been conduced on the lateral side of the berry, positioned on the base of the texture analyser **(Brummell et al., 2004)**.

$$W_{sk} = \int_0^{p_{sk}} F_{sk}\, dp. \qquad (1)$$

Whole berry mechanical properties were assessed using a compression test. Berries were compressed both in the equatorial position (perpendicular to berry height L, [mm]) and vertically along of the berry symmetry axis. The compression velocity was also 10 $mm \cdot s^{-1}$. The following mechanical parameters have been measured: crushing force F_c [N], the plate displacement at the crushing strength p_c [mm] and the berry crushing energy W_c [J = N·mm], see Eq. (2). The crushing force is the compression force that is necessary to cause the skin break when the first grape juice is coming out **(Brummell et al., 2004)**.

$$W_c = \int_0^{p_c} F_c\, dp. \qquad (2)$$

The results obtained were statistically analysed using the statistical toolbox of software MATLAB version 7.12.0.635 (R2011a) (The MathWorks, MA, USA). Evaluated were the means and standard deviations using ANOVA with subsequent Tukey's test at significance levels of $p < 0.05$.

RESULTS AND DISCUSSION

In the Figure 1 an example of the experimental record force F vs displacement p is shown. The same qualitative features exhibited all experimental records. The force increases up to some maximum value corresponding to the skin break force F_{sk}. The force is non-linear function of the displacement. This is slightly different result than that obtained e.g. by **Maury et al., (2009)** and/or **Río Segade et al., (2011)**. In these papers the considered dependence was linear.

The berry skin break force F_{sk} for different wine varieties is displayed in the Figure 2. This force decreases with the time of the harvesting. It means this force exhibits a good correlation with the content of total acids, see Figure 3. This dependence is different for the different wine varieties. It means the value of this force cannot be used for the identification of single varieties.

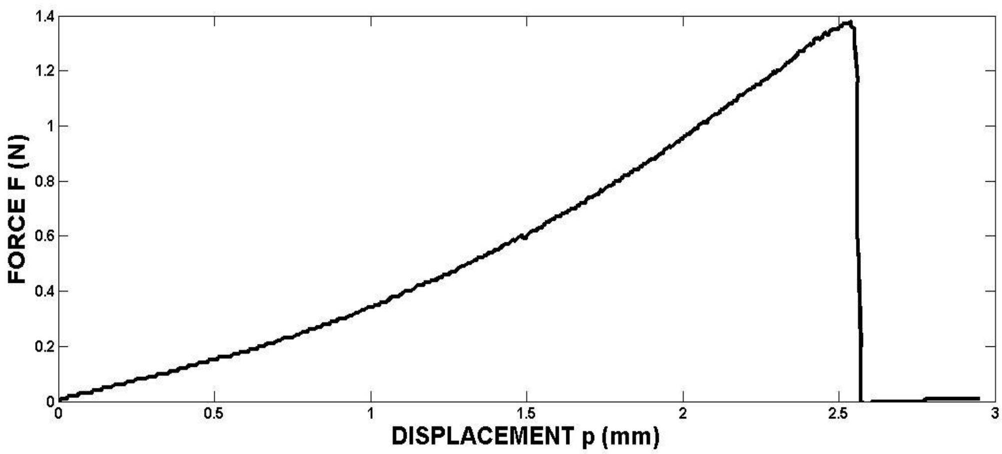

Figure 1 Example of the experimental record break force – displacement during the puncture test.

The dependence of the break force F_{sk} on the sugar content can be considered as a linear. The best correlation, i.e. higher than 0.85 have been observed for the following varieties: *Hibernal*, *Riesling*, *Malverina*, and *Cerason*. For the remaining grapevines the correlation coefficient was between 0.73 and 0.82. Nearly no correlation has been found between displacement at the skin break p_{sk} and the total sugars content. Very good correlation has been also found between the berry skin break energy W_{sk} and total content both of sugars and acids. Development of this energy during the harvest period is displayed in the Figure 4.

In the Figure 5 an example of the experimental record of the force F_c – displacement during the compression test is displayed. The qualitative features of this record are the same like in the case of the puncture test, see Figure 1. This conclusion is valid for both transversal and vertical tests and for all winegrape varieties.

The average values of the crushing force F_c for different wine varieties are displayed in the Figure 6.

This force F_c decreases with the time of the harvesting. Qualitatively the same dependence exhibits crushing force

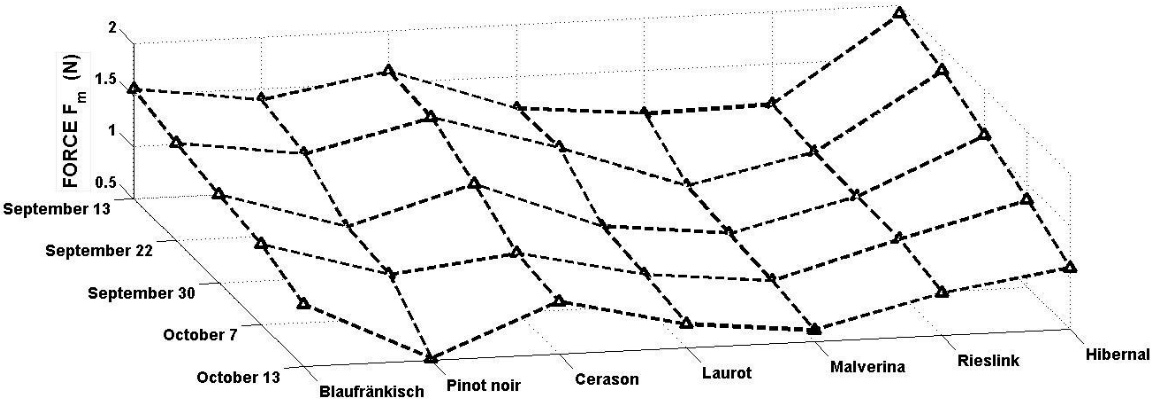

Figure 2 Skin break force evaluated from the puncture test.

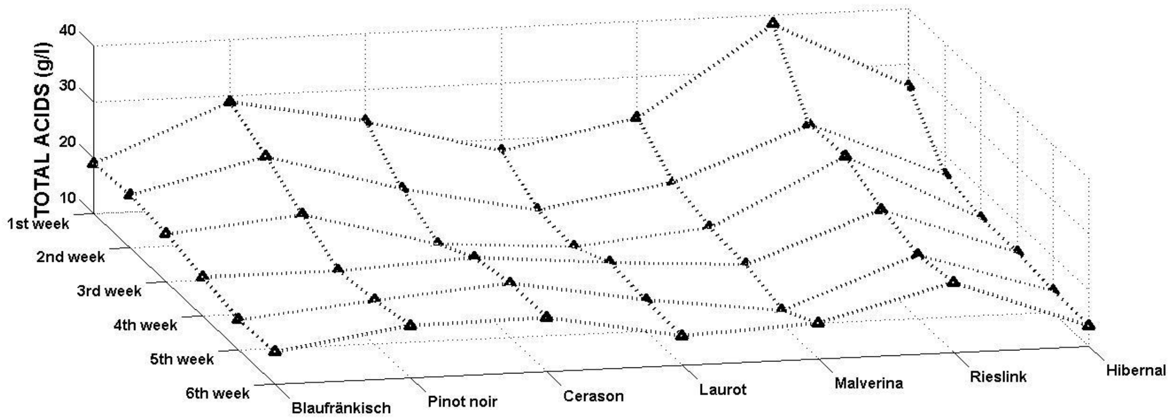

Figure 3 Content of total acids in grapes of tested varieties.

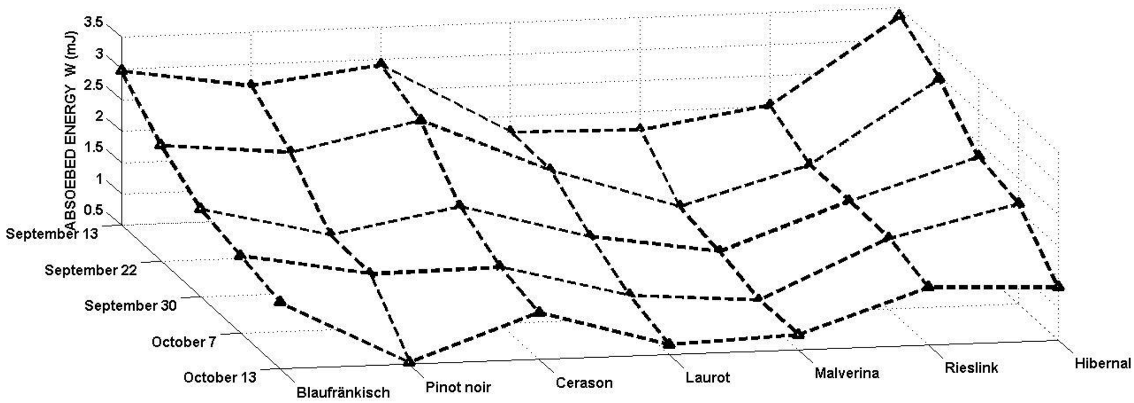

Figure 4 Berry skin break energy at the different days of the harvest.

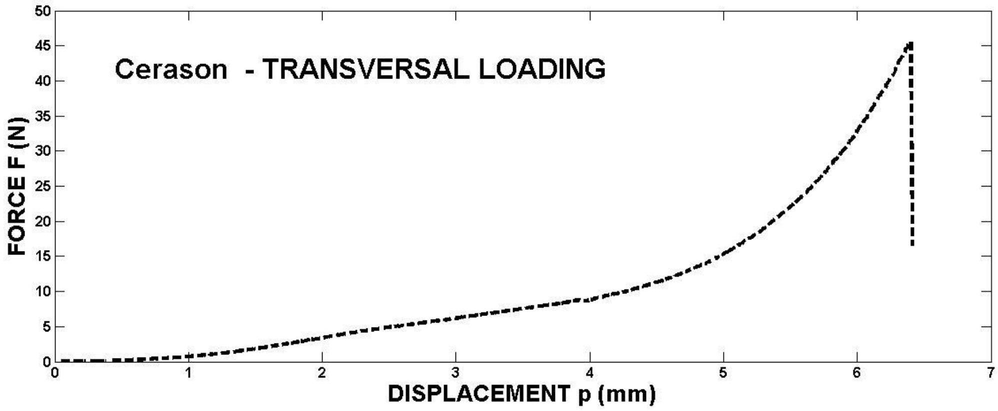

Figure 5 Example of the experimental record of the wine berry compression.

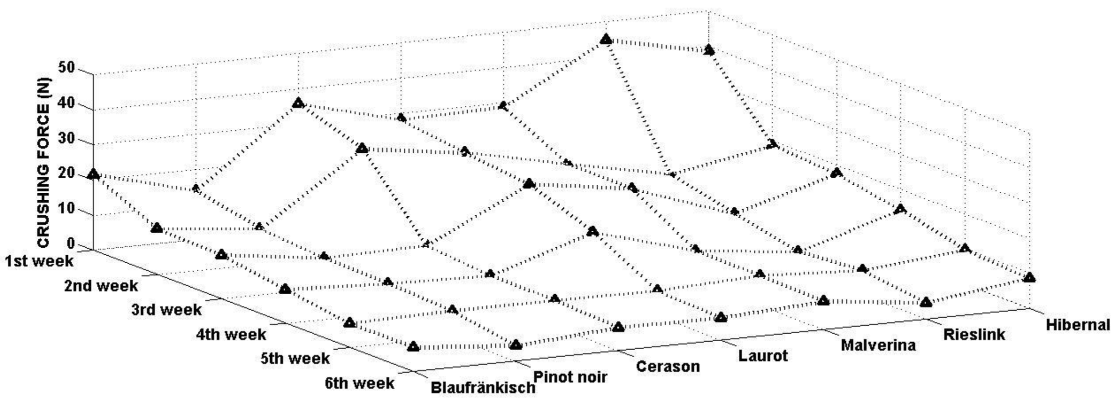

Figure 6 Average values of the crushing force during harvesting period – transversal compression.

obtained at the vertical loading. The differences between values of these force is described in the Table 1. In this Table 1 corresponds to the situation when the crushing force obtained during the transversal compression is higher than that obtained at the vertical compression. Zero corresponds to the opposite case.

It is evident that the crushing force corresponding to *Pinot Noir, Blaufränkisch* varieties evaluated at the lateral compression is higher than that evaluated at the vertical compression. The crushing force of remaining varieties does not exhibit this tendency. The crushing force is monotonically decreasing function of the harvesting time like the break force evaluated at the puncture test. If we perform a comparison of different varieties from the point of the value of the crushing force we obtain an arrangement given in the Table 2.

The minimum value of the crushing force exhibits *Pinot Noir* grapevine variety. The order of remaining varieties is different at different days of the harvesting. The arrangement made according to the crushing force evaluated at the lateral compression is different from that given in the Table 2, see Table 3.

The same arrangement according to the values of the break force evaluated at the puncture test is given in the Table 4.

The results are different from those obtained at the compression test. Qualitatively the same conclusions can be deduced from the values of the absorbed energy and from the values of the displacements at the crushing force. One can see that the critical values of the forces which describe the strength of the berry skin (puncture test) and the whole berry (compression test) gives a different order of grapevine varieties at different days of harvesting.

As it has been mentioned in the introduction, grape

Table 1 Comparison of crushing force for transversal and vertical compression.

Week	*Hibernal*	*Riesling*	*Malverina*	*Laurot*	*Cerason*	*Pinot Noir*	*Blaufränkisch*
1st	1	0	0	0	0	1	1
2nd	1	0	0	0	0	1	1
3rd	1	0	0	0	1	1	1
4th	1	1	1	0	1	1	1
5th	1	0	1	1	1	1	1
6th	0	1	0	1	1	1	1

Table 2 Order of grapevine varieties at the single data of their harvesting – vertical loading.

1st week September 4	2nd week September 13	3rd week September 22	4th week September 30	5th week October 7	6th week October 13
Riesling	*Riesling*	*Riesling*	*Riesling*	*Riesling*	*Riesling*
Malverina	*Malverina*	*Laurot*	*Laurot*	*Cerason*	*Hibernal*
Laurot	*Laurot*	*Malverina*	*Malverina*	*Malverina*	*Laurot*
Cerason	*Cerason*	*Pinot Noir*	*Pinot Noir*	*Laurot*	*Cerason*
Blaufränkisch	*Blaufränkisch*	*Blaufränkisch*	*Blaufränkisch*	*Pinot Noir*	*Malverina*
Hibernal	*Pinot Noir*	*Cerason*	*Cerason*	*Blaufränkisch*	*Pinot Noir*
Pinot Noir	*Hibernal*	*Hibernal*	*Hibernal*	*Hibernal*	*Blaufränkisch*

Table 3 Order of grapevine varieties at the single data of their harvesting – transversal loading.

1st week September 4	2nd week September 13	3rd week September 22	4th week September 30	5th week October 7	6th week October 13
Pinot Noir	*Pinot Noir*	*Pinot Noir*	*Riesling*	*Blaufränkisch*	*Pinot Noir*
Blaufränkisch	*Blaufränkisch*	*Cerason*	*Cerason*	*Riesling*	*Riesling*
Laurot	*Riesling*	*Riesling*	*Pinot Noir*	*Laurot*	*Laurot*
Malverina	*Hibernal*	*Blaufränkisch*	*Malverina*	*Cerason*	*Cerason*
Cerason	*Malverina*	*Hibernal*	*Blaufränkisch*	*Pinot Noir*	*Blaufränkisch*
Hibernal	*Laurot*	*Malverina*	*Hibernal*	*Malverina*	*Malverina*
Riesling	*Cerason*	*Laurot*	*Laurot*	*Hibernal*	*Hibernal*

Table 4 Order of grapevine varieties at the single data of their harvesting – puncture test.

2nd week September 13	3rd week September 22	4th week September 30	5th week October 7	6th week October 13
Malverina	*Malverina*	*Malverina*	*Malverina*	*Pinot Noir*
Riesling	*Riesling*	*Laurot*	*Laurot*	*Malverina*
Laurot	*Laurot*	*Pinot Noir*	*Pinot Noir*	*Laurot*
Pinot Noir	*Pinot Noir*	*Riesling*	*Riesling*	*Riesling*
Blaufränkisch	*Blaufränkisch*	*Cerason*	*Cerason*	*Cerason*
Cerason	*Cerason*	*Blaufränkisch*	*Blaufränkisch*	*Hibernal*
Hibernal	*Hibernal*	*Hibernal*	*Hibernal*	*Blaufränkisch*

maturity is associated with changes in the composition and structure of the cell wall of skin and pulp as well as in the structure of the tissue. Therefore, the test conducted on whole berry, which assess the parameters such as crushing strength etc., is actually the best test to monitoring the ripeness, although the values of parameters measured can be affected by rainfalls **(Malheiro et al., 2011; Bonada et al. 2015)**. In this type of test, pulp and skin data are aggregate. On the contrary, by puncture test conduced with thin rounded probe only skin characteristics can be defined. Actually, the break skin force F_{sk} could be considered an important parameter to be monitored for the assessment of the anthocyanins extractability. It means both tests must be used for the evaluation of the berry softening during the maturation.

CONCLUSION

A detail study of the mechanical characteristics of seven winegrape varieties during ripening has been performed. Results of the puncture test shows that there the skin break strength and the acidity content are monotonic functions of the time. The correlation between the skin break strength and the sugar content is significant namely for the varieties: *Hibernal, Riesling, Malverina,* and *Cerason*. The correlation for the remaining varieties is weaker. Very similar results are valid for the parameters of the compression test. Results of these tests are dependent on the loading orientation. The effect of this parameter is different at different stage of the ripening. Generally the results obtained in this work approved some previous hypothesis that mechanical texture parameters were able to show differences between grapes having different ripening level. In order to support results performed up to now it is necessary to perform some additional experiments with different values of compression velocities and with different diameters of the cylindrical needle probe.

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