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RELATIONSHIP BETWEEN VISCOSITY AND SUGAR CONTENT OF MUST DURING RIPENING PERIOD OF GRAPES

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ABSTRACT
The relationship between dynamic viscosity and sugar content of the must is important indicator during the ripening of the vine grapes. For the experiment were selected and used only grape vine varieties. The grape vine varieties are divided into blue and white. The varieties of Blaufränkisch, Blauer Portugieser, and Cabernet Moravia were used in the blue varieties. Representatives of the white varieties were used Pinot Blanc, Pinot Gris, and Sauvignon. Country of origin was the Czech Republic, wine region Moravia (sub-region Slovácko). The grapes were collected and analyzed four times week after week during their ripening period. After grapes harvesting the individual berries were cut out of grape using the scalpel. These berries were then weighed and then the must was squeezed using a mechanical presser. Weight of berries, dynamic viscosity (in shear strain rate 100 s^{-1}), sugar content, and density of must were measured and evaluated. From the values of berries weight it can be observed the variations in weight depending especially on the weather change – the water content in the berries. The observed sugar content did not change a lot during maturity, which can be explained by a more mature phase of the grapes. The results of viscosity and sugar content (for all varieties) demonstrate the viscosity dependence on the sugar content of must – with increasing viscosity of the must the sugar content of the must increase and conversely. The knowledge of the physico-mechanical properties os wine must is very important for for technocologists, producers, but also wine consumers.

Keywords: viscosity; sugar content; density; ripening; must; vine variety.

INTRODUCTION
Wine production in the Czech Republic has long been around 60 million litres, where 63% is production of white wine, 28% is red wine, and 9% is pink wine. The average annual consumption of wine has reached 20 litres per person **(Šrédl et al., 2017)**. For food quality is necessary knowledge of the properties of the raw materials and foodstuffs **(Nedomová, 2009; Severa et al, 2010; Božiková and Hlaváč, 2013)**. The same case is with wine, each grape and table grape varieties has specific properties and dispositions that make it unique. It is therefore necessary to know the characteristics of the individual grape varieties **(Kumbár and Votava, 2015; Hlaváč et al., 2016)**.

Grapes have a huge impact on the end product. The varietal diversity, together with the processing method and the yeast used, ensures some variability among products **(Mlček et al., 2018)**. Grape must is a juice containing a large amount of natural substances – contains water, sugars, acids, tannins, aromatics, nitrogen and minerals, dyes, enzymes, fatty substances, and waxes, see Table 1 **(Poracova et al., 2016)**.

Many ingredients of grape must are very valuable for human nutrition, especially for the natural content of easily extractable phenolic substances, the grape must has antioxidant properties. Therefore, this juice in the beverage industry is used to produce refreshing beverages and syrups **(Yadav et al., 2009; Iriti and Varoni, 2016)**.

Table 1 Substances of grape berries.

Substance	Content (mg/berry)
Water	750
Sugars	240
Acids	6
Mineral substances	5
Phenol substances	2
Fragrant aromatic substances	0.1
Nitrogenous substances	2

Sugar is produced in the grapes by CO_2 assimilation – photosynthesis. From the carbohydrates are then form organic acids in the grapes. These are, for example, tartaric acid, malic acid and succinic acid **(Flores et al., 2012)**. The sweet taste in grape must is caused by the two most common monosaccharides, D-glucose and D-fructose, with more than 90% soluble berries, see more in **Bangaraiah and Ashok Kumar (2017)**. The presence of carbohydrates directly affects the fullness, texture and extract of the future wine. Conversely, reducing carbohydrates results in bitterness, acidity, and tarseness. In mature berries, the sugar content across the varieties is above 250 $g.L^{-1}$ **(Delgado Cuzmar et al., 2018)**.

Scientific hypothesis

The main hypothesis of this work is to determine if the viscosity of the must is depend on the sugar content of the must from the grape berries. Experiment deals with the properties of must from six varieties of grapevine. The selected properties were carried out (in three weeks replicates) for the berries: sugar content, viscosity, and density of must. Observed was also berry weight. The results were subsequently evaluated, focusing on the viscosity dependence on the sugar content in must from grape berries.

MATERIAL AND METHODOLOGY

For the experiment were selected and used only grape vine varieties. The grape vine varieties are divided into blue and white. The varieties of Blaufränkisch, Blauer Portugieser, and Cabernet Moravia were used in the blue varieties. Representatives of the white varieties were used Pinot Blanc, Pinot Gris, and Sauvignon. Country of origin is the Czech Republic, wine region Moravia – sub-region Slovácko.

Grapes were collected in the four terms – September 4th, September 11th, September 18th, and September 25th in 2017. These terms correspond with mature period of these grape vine varieties **(Bautista-Ortín et al., 2006; Maoz eta l., 2018)**. After grapes harvesting the individual berries were cut out of grape using the scalpel. These berries were then weighed and then the must was squeezed using a mechanical presser. Immediately after then the must was analysed using several equipment and method.

Precision values of berries weight was carried out using digital scale GX-2000-EC (A&D, Japan) with accuracy 0.001 g. Sugar content in the must was measured using digital refractometer RDBS1-ATC (JLab, China) with automatic temperature compensation. In this meauserement the unit °Bx (degree of Brix) was used. The unit °Bx means same as g/100g – for example 25 °Bx expresses 25% sugar and 75% of water in 100g solution. The density of the must was measured using digital densitometer Densito 30 PX (Mettler Toledo, USA) with accuracy 0.001 $g.cm^{-3}$.

Viscosity measurements were carried out using the DV-2T rotary viscometer (Brookfield, USA) equipped with a coaxial cylinder sensor system with precision small samples adapter and standard spindle number 18 (according to Brookfield). The shear strain rate was set to 100 s^{-1} and the geometry of the measuring device it can be seen in **Kumbár and Dostál (2014)**.

All experiment were conducted at the room temperature 22 °C.

Statisic analysis

Statistical analysis were carried out using the software MATLAB® R2012a with Statistics toolbox (MathWorks, USA) – paired t-test and analysis of variance (ANOVA) with interaction, testing on the significance level of p = 0.05.

RESULTS AND DISCUSSION

The first step of processing results was to find correlation between density, sugar content, and dynamic viscosity of grape must.

Table 2 indicates whether the calculated paired correlation coefficient is statistically significant at the chosen significance level (p <0.05).

Table 2 Matrix with correlation coefficients of measured properties

Properties	Density	Sugar content	Viscosity
Density	1.00	**0.98**	**0.57**
Sugar content	**0.98**	1.00	**0.56**
Viscosity	**0.57**	**0.56**	1.00

The bold values in the Table 2 represents a statistically significant correlations on the level of significance p = 0.05.

The result values of all analysis and measurements are shown in the Table 3.

From the values of berries weight could be observed the variations in weight depending especially on the weather changes which caused the water content in the grape berries (**McCarthy and Coombe, 199**9; **Auzmendi and Holzapfel, 2016**).

For each of six grape vine varieties was created the graph illustrated the dependence of the dynamic viscosity and the sugar content of grape must, see Figure 1 (blue varietes) and Figure 2 (white varietes).

Obtained trends were modelled using the basic mathematical model – linear function – which can be describe:

$$SC = a \cdot \eta + b \tag{1}$$

Where SC [°Bx] is sugar content, η is dynamic viscosity [mPa·s], a [°Bx·(mPa·s)$^{-1}$] and b [°Bx] are regression coefficients. In the Table 4 there are values of regression coefficients a, b and coefficients of determination R^2 of the used mathematical model.

The most varieties shows the same trend – with the gradual maturation the dynamic viscosity decreased and the sugar content was not changed significantly (p <0.05). Due to non-grading sugar content, the dynamic viscosity dependence on sugar content cannot be directly assessed, but the data obtained for this experiment suggest that the dynamic viscosity should increase with increasing sugar content. These trends agree with the studies **Lopéz et al. (1989)**, **Nurgel and Pickering (2005)**, **Trávníček et al. (2016)** and **Nedomová et al. (2017)**. The other paper witch deals with the ice wines **(Cliff et al., 2002)** supplement the claim that increasing the sugar content affects the viscosity increase over density. At the other hand, there were published several studies dealing with a sucrose of fruit juice where different sugar contents have no influence on viscosity, see **Neto et al. (2005)**, **Tarzia et al. (2010)**, and **Steiner et al. (2011)**.

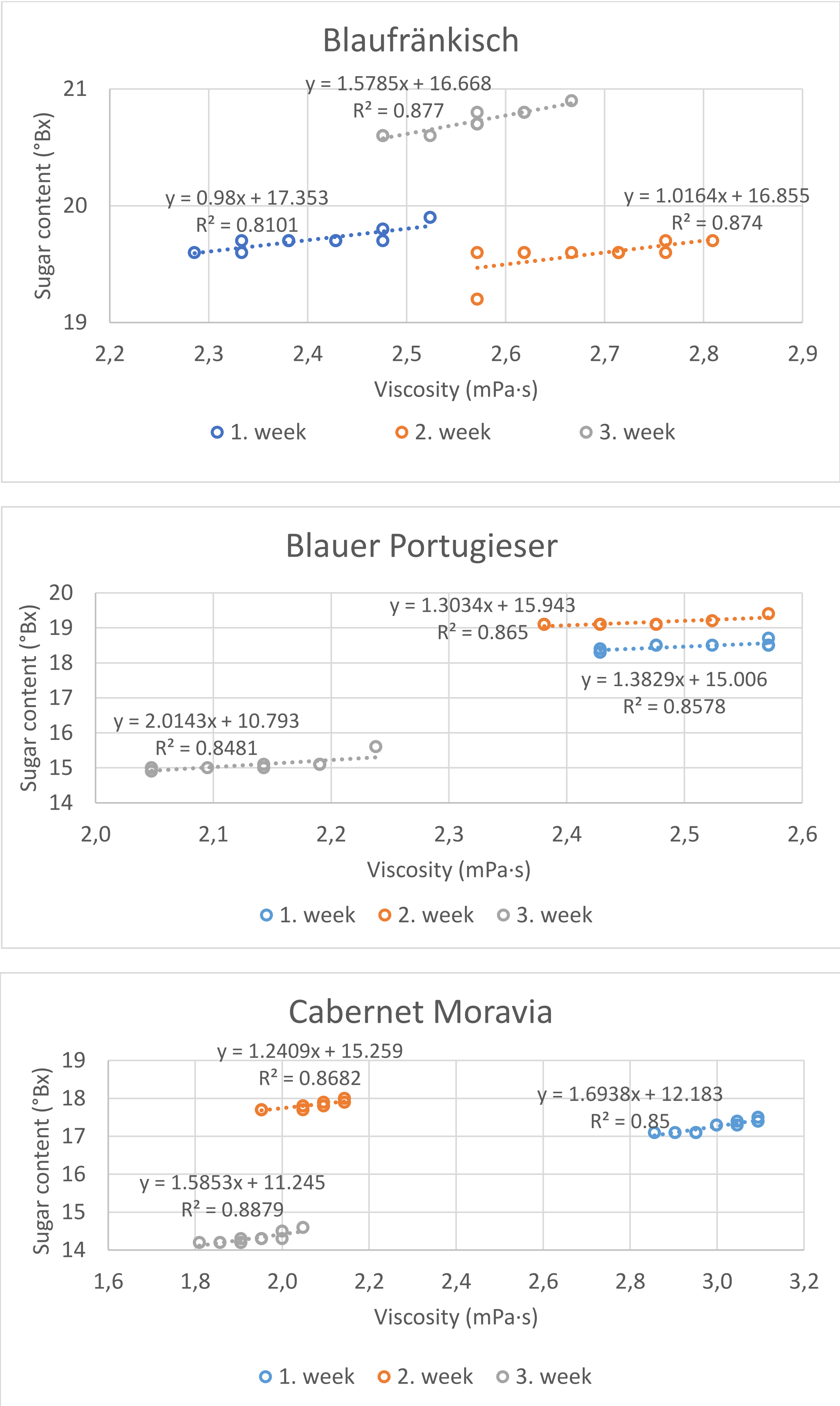

Figure 1 Dependence viscosity and sugar content of must – Blaufränkisch, Blauer Portugieser, Cabernet Moravia.

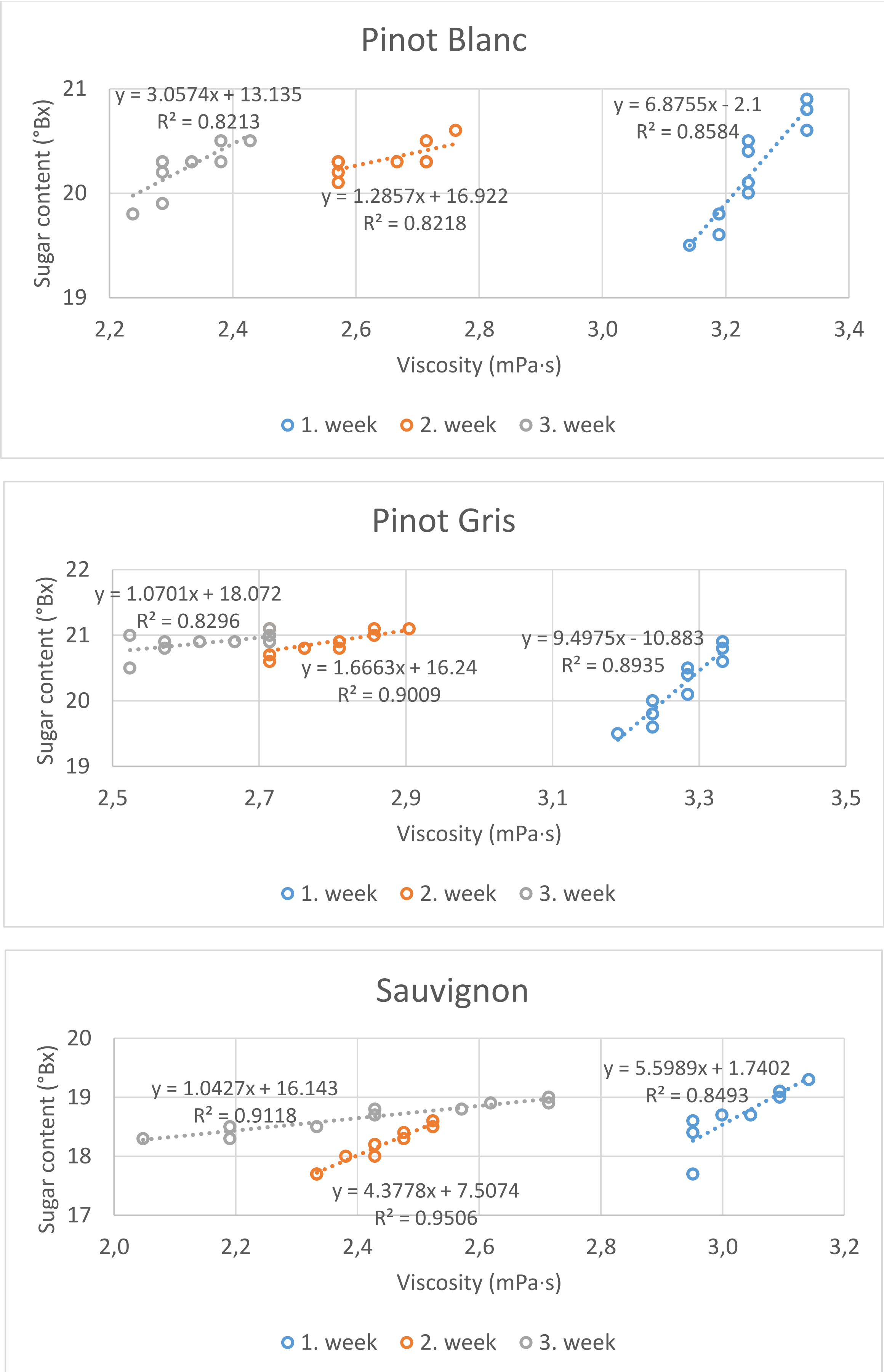

Figure 2 Dependence viscosity and sugar content of must – Pinot Blanc, Pinot Gris, Sauvignon.

Table 3 Experimental values (n = 10; results are shown as average ±standard deviation).

Date	Properties	Units	Blaufränkisch	Blauer Portugieser	Cabernet Moravia	Pinot Blanc	Pinot Gris	Sauvignon
04.09.2017	Berry weight	g	-		2.374 ±0.1584	1.567 ±01432	1.972 ±0.2298	1.877 ±0.2148
	Sugar content	°Bx	-		17.27 ±0.16	20.22 ±0.49	20.62 ±0.13	18.77 ± 0,47
	Density	kg.m^{-3}	-		1074.13 ±0.19	1089.67 ±0.41	1089.67 ±0.41	1075.99 ±0.07
	Viscosity	mPa·s	-		3.004 ±0.085	3.246 ±0.067	3.275 ±0.049	3.042 ±0.073
11.09.2017	Berry weight	g	2.82 ±0.3788	2.886 ±0.2954	1.995 ±0.3619	1.947 ±0.2708	1.775 ±0.3064	1.302 ±0.3086
	Sugar content	°Bx	19.71 ±0.09	18.47 ±0.12	17.80 ±0.11	20.32 ±0.14	20.89 ±0.18	18.16 ±0.31
	Density	kg.m^{-3}	1082.50 ±0.05	1077.10 ±0.07	1075.08 ±0.08	1086.83 ±0.05	1088.77 ±0.05	1076.74 ±0.07
	Viscosity	mPa·s	2.405 ±0.075	2.505 ±0.064	2.048 ±0.074	2.643 ±0.079	2.790 ±0.068	2.433 ±0.069
18.09.2017	Berry weight	g	2.766 ±0.3252	2.764 ±0.5826	2.310 ±0.3086	2.216 ±0.2321	2.046 ±0.2287	1.828 ±0.2372
	Sugar content	°Bx	19.58 ±0.14	19.14 ±0.10	14.31 ±0.14	20.24 ±0.23	20.89 ±0.16	18.67 ±0.25
	Density	kg.m^{-3}	1084.76 ±0.17	1081.17 ±0.53	1059.63 ±0.21	1087.67 ±0.66	1089.39 ±0.14	1080.51 ±0.43
	Viscosity	mPa·s	2.681 ±0.084	2.452 ±0.060	1.933 ±0.072	2.324 ±0.059	2.633 ±0.081	2.424 ±0.233
25.09.2017	Berry weight	g	2.426 ±0.3211	2.300 ±0.3498		-		
	Sugar content	°Bx	20.72 ±0.10	15.09 ±0.19		-		
	Density	kg.m^{-3}	1090.76 ±0.26	1065.54 ±0.61		-		
	Viscosity	mPa·s	2.567 ±0.061	2.133 ±0.070		-		

Table 4 Regression coefficients and coefficient of determination.

Variety	Week	*a* (°Bx·(mPa·s)$^{-1}$)	*b* (°Bx)	R^2
Blaufränkisch	1.	0.9800	17.353	0.8101
	2.	1.0164	16.855	0.8740
	3.	1.5785	16.668	0.8770
Blauer Portugieser	1.	1.3829	15.006	0.8578
	2.	1.3034	15.943	0.8650
	3.	2.0143	10.793	0.8481
Cabernet Moravia	1.	1.6938	12.183	0.8500
	2.	1.2409	15.259	0.8682
	3.	1.5853	11.245	0.8879
Pinot Blanc	1.	6.8755	-2.100	0.8584
	2.	1.2857	16.922	0.8218
	3.	3.0574	13.155	0.8213
Pinot Gris	1.	9.4975	-10.883	0.8935
	2.	1.6663	16.240	0.9009
	3.	1.0701	18.072	0.8296
Sauvignon	1.	5.5989	1.7402	0.8493
	2.	4.3778	7.5074	0.9506
	3.	1.0427	16.143	0.9118

CONCLUSION

At the present time it is necessary to know up-to-date information from scientific research in the food industry, because the characteristics and understanding of the properties of the foodstuffs is the key to product innovation and optimization of industrial foodstuff processing. Of course, this information is also helpful in the field of winemaking for the development of new equipment and equipment, in particular the chemical and thermos-physical properties of the wine.

From the values of berries weight could be observed the variations in weight depending especially on the weather changes – the water content in the berries.

The observed varieties were shown the same trend – with the gradual maturation the viscosity decreased and the sugar content was not changed significantly (p <0.05).

The sugar content was not changed a lot during ripening period, which can be explained by the higher degree of ripeness of the grapes.

At the finally, the relationship between the viscosity and sugar content demonstrate the viscosity dependence on the sugar content of must – with increasing viscosity of the must the sugar content of the must increase and conversely (for all varieties).

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