Influence of terroir on the concentration of selected stilbenes in wines of the cv. Riesling in the Czech Republic

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Abstract

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The relationship between the terroir and the quality of grapes and/or wines is used in wine authenticity determination based on geographical origin. The phenolic compounds in grapes and wines are probably related to the terroir. The subject of the study was the analysis of 43 wines of the cv. Riesling from six wine-growing sub-regions, 16 different localities and four vintages to determine the content of *trans*-resveratrol, *trans*-piceid, *cis*-resveratrol and *cis*-piceid. The analyses were performed using an HPLC method. A relationship was observed between *trans*-resveratrol concentration in wines and wine-growing locality. The concentration of *trans*-resveratrol ranged from 0.04 to 0.82 mg/l with mean concentration of 0.28 mg/l. The highest concentrations of *trans*-resveratrol were found in wines from the localities Podmolí (0.66 mg/l), Hostěradice (0.64 mg/l and 0.82 mg/l), Mělník (0.59 mg/l) and Litoměřice (0.57 mg/l). Differences were also found in the relationship between *trans*-resveratrol and wine-growing sub-regions. Relationships between *trans*-piceid, *cis*-resveratrol or *cis*-piceid concentration and wine terroir were not demonstrated. The results of this study demonstrated the capability to differentiate the wine terroir using the *trans*-resveratrol concentrations.

Keywords: authenticity; geographical origin; HPLC; resveratrol; winemaking

The terroir is the natural locality of each plant of grapevine in a vineyard. Each terroir is influenced by climatic, geological and soil factors, but also by human activity when treating the vineyard. Each grape produced in a specific terroir reflects the locality in its chemical composition. It is possible to define the terroir as an interactive ecosystem in the given locality comprising the climate, the soil and the grapevine (Seguin 1986). Therefore the quality of wine depends on the terroir. The terroir differs according to the area, and therefore it has a geographical size. The capability of each terroir to produce different wine can be evaluated using the analysis of wine produced under microvinification or real vinification conditions (van Leeuwen et al. 2010).

Wine is a product that has very close connection to its place of origin and the origin of the wine is often used as indicator of quality (Atkin, Johnson 2010).

Analysis of the relationships between Riesling wines and terroir is a very common theme of many recent investigations (Douglas et al. 2001; Reynolds et al. 2007, 2010a, b; Willwerth et al. 2010). These studies focused upon relationships between soil moisture, vine water status, and their interrelationships with secondary metabolites such as monoterpenes.

Phenolic compounds are also secondary metabolites, some of which originate in chemical and biochemical reactions during the winemaking process (Li et al. 2010). Thus the composition and the concentration of phenolic compounds mostly depend on the vineyard.

Nowadays there are many existing analytical procedures which enable the classification of wine for the purpose of wine authenticity identification and it is also possible to use *trans*-resveratrol to determine the geographical origin of wine (Arvanitoyannis 2010). Phenolic compounds are secondary metabolites naturally occurring in grapes; they are subsequently released or transformed in winemaking technology.

Resveratrol and its derivatives also are the main phytoalexins produced by the grapevine. Grapevine phytoalexins belong to the group of stilbenes, the structure of which is based on *trans*-resveratrol. Stilbenes belong to non-flavonoid phenolic compounds.

Stilbenes are chemical compounds naturally present in many plant families as Pinaceae, Myrtaceae, Fagaceae, Liliaceae, Moraceae, Papilionaceae and Vitaceae. They are synthesized by several species within the family of Vitaceae including *Vitis vinifera*. Stilbenes are compounds with antifungal activity which enable plants to fight off a pathogen attack (Bavaresco, Fregoni 2001).

Health promoting effects of wine consumption are related to phenolic compounds naturally present in grapes and wine, and their antioxidant properties. Antioxidants are compounds which can eliminate free radicals contributing to the process of ageing and the cardiovascular and tumour diseases development. Moderate consumption of alcoholic beverages, like in the case of wine, has an effect on lowering a risk of cardiovascular diseases in comparison to abstainers and hard drinkers (Stockley, Hoj 2005). In the past, a positive effect of resveratrol against tumour diseases (Jung et al. 2006; Waffo-Teguo et al. 2008) and cardiovascular diseases (Falchi et al. 2006) and contribution on human-organism ageing retardation were proved (Rodriguez-Vaquero et al. 2007). The potential health benefits of resveratrol and its derivatives have encouraged enhanced research to activity in terms of the presence of these compounds in grapes and wines.

Resveratrol exists in two isomer forms (*cis* and *trans*). 3-O-β-D-glucosides of *cis*- and *trans*-resveratrol are called piceids (Rentzsch et al. 2009). *Trans*-resveratrol, *trans*- and *cis*-piceid were identified in grapes (Bavaresco et al. 2007). *Cis*-resveratrol is not present in grapes, but only in wine (Waterhouse 2002). It results from the fact that *cis*-resveratrol is formed by photochemical isomerization of *trans*-form to the *cis*-form during the winemaking process (Ali et al. 2009). Besides the berries, the derivates of resveratrol are also present in grape leaves (Bábíková et al. 2008) and grape rachis (Careri et al. 2004). The quantity of resveratrol in grapes and wines depends on the grapevine variety (Chafer et al. 2005; Cho et al. 2006; Moreno et al. 2008), climatic conditions of the locality (Perrone et al. 2007), UV-radiation (Adrian et al. 2000; Cantos et al. 2003; Creasy, Creasy 2003) and oenological methods used in wine production (Vrhovsek et al. 2002; Gambuti et al. 2004).

The aim of the study was to determine the concentrations of *trans*-resveratrol, *cis*-resveratrol, *trans*-piceid and *cis*-piceid in a collection of 43 Riesling wines from different localities in the Czech Republic, and on the basis of the results to evaluate the influence of the terroir on the concentration of these compounds in the individual wines. A further objective of this study was to explore the possibility of applying these results to wine authenticity determination on the basis of the geographical origin.

MATERIAL AND METHODS

The study was performed on 43 Riesling wine samples. The wine came from 16 different localities, six wine-growing sub-regions and from 2005, 2006, 2007 and 2008 vintages (Table 1).

Chemicals

Using HPLC method, all wines were analysed in terms of four stilbenes: *trans*-resveratrol, *cis*-resveratrol, *trans*-piceid and *cis*-piceid. Acetonitrile (ACN) and methanol (MeOH) of HPLC grade were obtained from VWR International (Darmstadt, Germany) for use in the mobile phase. *Trans*-resveratrol, *trans*-piceid (Polydatin) and perchloric acid were purchased from the Sigma-Aldrich (Saint Louis, USA).

Sample treatment

The wines were centrifuged (3,000× g; 6 min) and diluted by equal volume of 100mM of perchloric acid. The treated sample was directly used for HPLC analysis.

HPLC analyses

The individual forms of resveratrols and picieds were analysed by Shimadzu LC-10A system (Shimadzu, Kyoto, Japan) comprised of two LC-10ADvp pumps (Shimadzu, Kyoto, Japan) enabling binary high pressure gradient, a column thermostat CTO-10ACvp (Shimadzu, Kyoto, Japan)

Table 1. Values of *trans*-resveratrol, *trans*-piceid, *cis*-resveratrol and *cis*-piceid in individual wines of cv. Riesling in the Czech Republic (mg/l)

Sample	Locality	Sub-region	Vintage	*Trans*-resveratrol	*Trans*-piceid	*Cis*-resveratrol	*Cis*-piceid
1	Popice	Mikulov	2005	0.29	0.20	0.12	0.28
2	Popice	Mikulov	2006	0.07	0.07	0.04	0.10
3	Popice	Mikulov	2007	0.18	0.13	0.14	0.23
4	Popice	Mikulov	2008	0.14	0.11	0.16	0.26
5	Žarošice	Slovácko	2005	0.21	0.01	0.37	0.15
6	Žarošice	Slovácko	2006	0.18	0.13	0.07	0.16
7	Žarošice	Slovácko	2007	0.35	0.16	0.16	0.24
8	Žarošice	Slovácko	2008	0.19	0.18	0.19	0.45
9	Archlebov	Slovácko	2007	0.04	0.06	0.06	0.14
10	Archlebov	Slovácko	2008	0.21	0.22	0.14	0.40
11	Mikulov	Mikulov	2007	0.16	0.02	0.08	0.05
12	Mikulov	Mikulov	2008	0.12	0.05	0.05	0.10
13	Přítluky	Velké Pavlovice	2006	0.17	0.02	0.09	0.04
14	Přítluky	Velké Pavlovice	2007	0.16	0.04	0.09	0.10
15	Přítluky	Velké Pavlovice	2008	0.43	0.27	0.48	0.71
16	Syrovín	Slovácko	2005	0.20	0.02	0.28	0.06
17	Syrovín	Slovácko	2006	0.20	0.02	0.25	0.06
18	Syrovín	Slovácko	2008	0.21	0.19	0.24	0.44
19	Znojmo	Znojmo	2005	0.23	0.14	0.02	0.04
20	Znojmo	Znojmo	2006	0.13	0.08	0.08	0.17
21	Znojmo	Znojmo	2007	0.10	0.06	0.12	0.19
22	Podmolí	Znojmo	2006	0.66	0.09	0.25	0.13
23	Podmolí	Znojmo	2007	0.37	0.05	0.16	0.06
24	Podmolí	Znojmo	2008	0.43	0.17	0.22	0.27
25	Stošíkovice	Znojmo	2006	0.08	0.05	0.02	0.05
26	Stošíkovice	Znojmo	2007	0.37	0.05	0.20	0.08
27	Hostěradice	Znojmo	2005	0.64	0.23	0.12	0.14
28	Hostěradice	Znojmo	2006	0.82	0.28	0.12	0.14
29	Tasovice	Znojmo	2007	0.45	0.22	0.11	0.20
30	Tasovice	Znojmo	2008	0.26	0.10	0.18	0.19
31	Velké Žernoseky	Litoměřice	2005	0.19	0.11	0.06	0.08
32	Velké Žernoseky	Litoměřice	2006	0.23	0.27	0.16	0.45
33	Velké Žernoseky	Litoměřice	2007	0.10	0.06	0.05	0.10
34	Roudnice n/L	Litoměřice	2005	0.21	0.10	0.08	0.07
35	Roudnice n/L	Litoměřice	2006	0.32	0.26	0.07	0.17
36	Roudnice n/L	Litoměřice	2007	0.55	0.06	0.59	0.13
37	Litoměřice	Litoměřice	2006	0.57	0.18	0.26	0.21
38	Litoměřice	Litoměřice	2007	0.42	0.16	0.52	0.39
39	Mělník	Mělník	2006	0.59	0.13	0.16	0.09
40	Mělník	Mělník	2007	0.32	0.06	0.02	0.01
41	Most	Litoměřice	2005	0.08	0.06	0.02	0.03
42	Most	Litoměřice	2006	0.16	0.06	0.08	0.06
43	Most	Litoměřice	2007	0.11	0.04	0.15	0.13

Table 2. The gradient program of HPLC method for analysis resveratrols and piceids in Czech Riesling wines (%)

Time (min)	Solvent A ($15mM\ HClO_4$)	Solvent B ($15mM\ HClO_4$, 10% methanol, 50% acetonitrile)
0.00	95	5
20.00	70	30
30.00	55	45
35.00	30	70
37.00	0	100
38.00	0	100
38.01	100	0
38.49	100	0
38.50	95	5
45.00	95	5

with manual injection Rheodyne valve (Rheodyne, Rohnert Park, USA) and a photodiode-array detector SPD-M10Avp (Shimadzu, Kyoto, Japan). The system controlling and the evaluation of analyses were performed using the program LCsolution (Shimadzu, Kyoto, Japan).

The separation was carried out on the column Alltech Alltima C18 3 µm (150 mm × 3 mm, I.D.) (Deerfield, USA) protected by pre-column with the same stationary phase (7.5 mm × 3 mm, I.D.) and tempered to 60°C. The injection volume of the sample was 20 µl. The flow rate of the mobile phase represented by binary gradient was 0.6 ml/min. A two-phase gradient program was utilized (Table 2).

The total cycle time per sample was 45 min. Data were collected within the range of 200–520 nm at a resolution of 1.2 nm for 40 min. The quantification was carried out at 285 nm for *cis*-isomers and 310 nm for *trans*-isomers.

Calibration

The calibration curves for *trans*-resveratrol and *trans*-piceid were made on the basis of the peak area measurement of the standard solutions. The standard solutions were obtained by diluting the stock solutions of *trans*-resveratrol or *trans*-piceid concentration of 100 mg/l in methanol in order to cover the concentration range from 0.1 to 10 mg/l. All samples were stored in a freezer at –20°C.

Commercial standards of *cis*-resveratrol and *cis*-piceid are not available. These compounds were obtained by photo-isomerization of *trans*-resveratrol stock solutions which were exposed to solar radiation (over one hour period). After 10 min of exposure, 80–90% of *trans*-resveratrol was transformed into *cis*-resveratrol (Romero-Pérez et al. 1996). The amount of the formed *cis*-isomer was calculated on the basis of the loss of the *trans*-isomer.

Statistical analysis

The results were expressed as mean values complemented by corresponding standard deviations. The first step in the analysis of the data was to apply the one-way analysis of variance (ANOVA), to determine, for each element, the main effect of the locality and of the sub-region on resveratrols and piceids of wines. Depending on the number of discrimination variables utilized, subsequent evaluation was carried out by the Tukey's test ($p > 0.01$), which is a suitable method for one discriminating variable, as occurred in this study.

RESULTS AND DISCUSSION

In total, 43 samples of Riesling from 16 different localities taken from six different wine-growing sub-regions in the Czech Republic were analysed (Table 1).

The concentration of *trans*-resveratrol for these 43 wines ranged from 0.04 mg/l (sample 9, locality Archlebov, vintage 2007) to 0.82 mg/l (sample 28, locality Hostěradice, vintage 2006). The average concentration of resveratrol was 0.28 mg/l. The highest concentrations of *trans*-resveratrol were found in wines from locality Podmolí (sample 22), Hostěradice (samples 27, 28), Mělník (sample 39) and Litoměřice (sample 37). On the other hand, the lowest quantities of *trans*-resveratrol were found in wines from locality Popice (sample 2), Most (sample 41) and Stošíkovice (sample 25).

Wines of the Riesling cv. in the Czech Republic were also investigated by the analysis of 76 samples of wine (Faitová et al. 2004). The concentration of *trans*-resveratrol in samples from the Bohemian wine-growing region ranged from 0.033 to 0.421 mg/l with a mean value of 0.117 mg/l. The concentration of *trans*-resveratrol in samples from the Moravian wine-growing region ranged from 0.033 to 0.875 mg/l with a mean value of 0.123 mg/l. The mean values in that study are lower than those of our current study. Wines from Riesling originating in the Czech Republic were also analysed in another study with the results ranging from 0.2 to 0.8 mg/l of

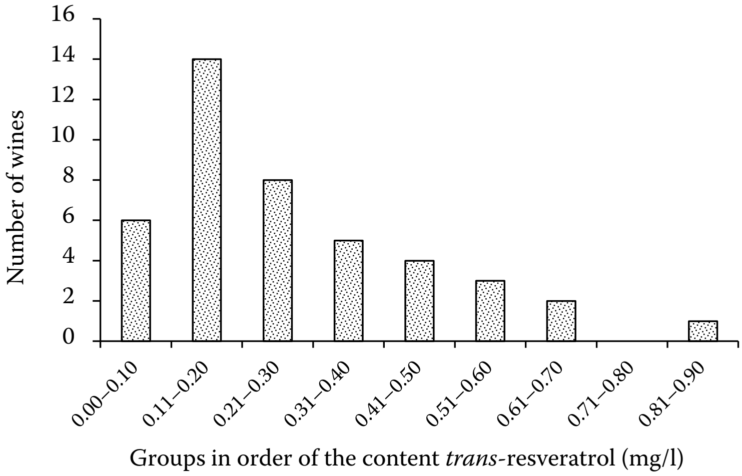

Fig. 1. The incidence of Czech Riesling wines in individual groups in order of the concentration of *trans*-resveratrol

trans-resveratrol (Šmidrkal et al. 2001). These values correspond with the results of our current study.

White wines contain much lower concentrations of resveratrol compared to red wines (Jeandet et al. 1993, 1995; Pezet et al. 1994; Goldberg et al. 1995).

Higher concentrations of *trans*-resveratrol (10 mg/l) are usually present in wines where the contact of the must and skin during the winemaking process occur, particularly during fermentation, whereas lower concentrations (0.3 mg/l) are usually found in white and rosé wines (Rodriguez-Delgado et al. 2002). The mean value in Riesling wines (0.28 mg/l) in our current study fully confirms this fact.

The values of *trans*-resveratrol in wines from the Czech Republic also correspond with the values for wines from Germany. The concentration of *trans*-resveratrol in white German wines ranged from 0 to 0.7 mg/l with a mean value of 0.3 mg/l (Nikfardjam et al. 1999).

On the other hand, the concentrations of *trans*-resveratrol in wines from south wine-growing areas are significantly lower as in the case of white wines from Canary Islands, where the concentration of *trans*-resveratrol varied from 0.07 to 0.13 mg/l (Rodriguez-Delgado et al. 2002).

The distribution of the wines with respect to the concentration of *trans*-resveratrol followed a parabolic pattern, with the highest incidence of wines found in the group 0.11–0.20 mg/l of *trans*-resveratrol, concentration which involved 14 wine samples (Fig. 1). The second most numerous group was that of 0.21–0.30 mg/l, which comprised eight wines. More than half the samples of wines contained 0.11–0.30 mg/l of *trans*-resveratrol. With increasing concentration of *trans*-resveratrol the number of wines progressively decreased. The highest incidence of wines with *trans*-resveratrol concentrations higher than 0.31 mg/l were those from Znojmo and Litoměřice sub-regions.

The concentration of *trans*-piceid in the wine samples ranged from 0.01 mg/l (sample 5, locality Žarošice, vintage 2005) to 0.28 mg/l (sample 28, locality Hostěradice, vintage 2006) with the mean value of 0.12 mg/l. Wines with the highest concentrations of *trans*-piceid came from Hostěradice locality.

The concentration of *cis*-resveratrol ranged from 0.02 mg/l (sample 19, locality Znojmo, vintage 2005; sample 25, locality Stošíkovice, vintage 2006; sample 40, locality Mělník, vintage 2006 and sample 41, locality Most, vintage 2005) to 0.59 mg/l (sample 36, locality Roudnice n/L., vintage 2007). The mean value was 0.16 mg/l. The concentration of *cis*-piceid ranged from 0.01 mg/l (sample 40, locality Mělník, vintage 2007) to 0.71 mg/l (sample 15, locality Přítluky, vintage 2008) with a mean value of 0.18 mg/l. The results indicate higher concentrations of *cis*-piceid compared to *trans*-piceid in these wines, which is in contradiction with previous findings that reported higher concentrations of *trans*-piceid (La Torre et al. 2006). Significant correlations were also found for *trans*-piceid × *cis*-piceid (0.68, $p > 0.01$), *trans*-resveratrol × *trans*-piceid (0.51, $p > 0.05$) and *cis*-resveratrol × *cis*-piceid (0.48, $p > 0.05$) concentrations.

The highest mean value of all wines was found in the case of *trans*-resveratrol which can be considered as a predominant phenolic compound within the group of stilbenes in Riesling wines. Higher concentrations of *cis*-resveratrol compared to *trans*-resveratrol were found in some wines. These results corroborate findings of that showed high concentrations of *cis*-resveratrol in Serbian wines, and support the theory that resveratrol is produced as the *trans*-isomer and after its isomerization, particularly during fermentation, the *cis*-isomer is

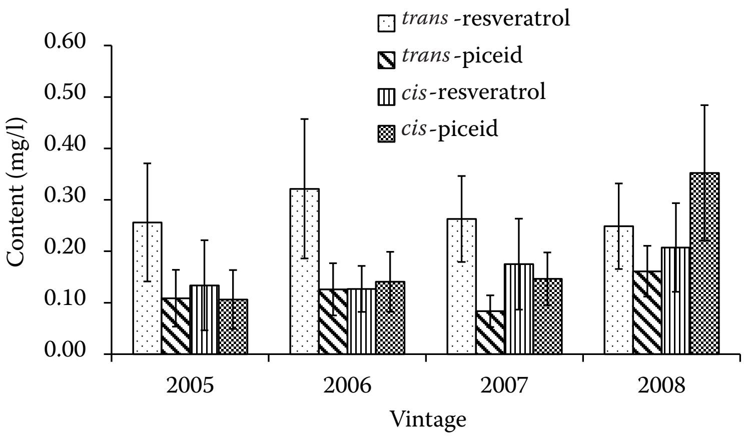

Fig. 2. Evaluation of the vintage influence on *trans*-resveratrol, *trans*-piceid, *cis*-resveratrol and *cis*-piceid concentrations (mean ± S.D.) in individual wines cv. Riesling from the Czech Republic and differences at significance $p < 0.01$

formed (Dekič et al. 2008). The results do not correspond with findings that *trans-* and *cis*-piceids are significant compounds in white wines (Romero-Pérez et al. 1996). In our Riesling wines, these compounds were detected on average in lower concentrations compared to those of resveratrols.

The influence of vintage on the concentration of stilbenes was also investigated in the wines. However, an influence of vintage was proved only in the case of *cis*-piceid (Fig. 2).

An interesting trend was seen in the case of *cis*-piceid. The concentration of *cis*-piceid was the highest in 2008 and progressively decreases towards the year 2005. A similar trend was also seen in the case of another isomer, *cis*-resveratrol. Its concentration is progressively decreased from 2008 towards 2006 and afterwards became stable.

But the main objective of this study was to evaluate the influence of locality on the concentration of individual stilbenes and to use these phenolic compounds to determine the wine authenticity on the basis of its geographical origin. The concentration of phenolic compounds can differ among individual localities, so therefore it is possible to use it to differentiate wines according to the growing locality (Rodriguez-Delgado et al. 2002). Phenolic compounds were used in the geographical origin differentiation of wines from South Africa (de Villiers et al. 2005). Therefore our wines were studied on the basis of individual localities and subsequently more general on the basis of sub-regions. This idea of wine authenticity evaluation on the basis of geographical origin is also recommended by Charlton et al. (2010) who stated that chemical composition was able to give perfect indication of wine origin but only if the origin was significant with higher level of specification than the individual geographical localities. The best determination of the region of origin is possible on the basis of analytical profile of the wine.

Mean values of the concentration of the analysed stilbenes on the basis of individual localities showed that there was no influence of locality on the amounts of *trans*-piceid, *cis*-resveratrol and *cis*-piceid (Table 3). In the case of *trans*-resveratrol, the highly significant influence of the locality on its concentration was observed. Therefore it might possible to use *trans*-resveratrol to evaluate the wine authenticity on the basis of geographical origin. The highest mean concentration of *trans*-resveratrol was found in wines from Hostěradice (0.73 mg/l), Litoměřice (0.50 mg/l) and Podmolí (0.49 mg/l) localities. On the other hand, very low concentrations were found in the case of Archlebov (0.13 mg/l), Mikulov (0.14 mg/l) and Most (0.12 mg/l) localities. The Hostěradice locality was substantially different from all other localities except for the Litoměřice locality. A considerable difference was also found in the case of the Podmolí locality. The locality Most was situated on the other side of the spectrum with a low concentration of *trans*-resveratrol which was substantially different from all the other localities, followed by Archlebov, Mikulov, Popice and Znojmo.

Interesting results also expose the comparison of wines according to sub-regions (Table 4). The influence of sub-regions on concentration of *trans*-resveratrol was substantial. Values for *trans*-piceid, *cis*-resveratrol and *cis*-piceid did not differ among individual localities and therefore the influence of terroir on their concentration in wines was not observed. The highest concentration of *trans*-resveratrol was found in wines from wine-growing sub-regions Mělník (0.46 mg/l) and Znojmo (0.38 mg/l). The sub-region with the lowest concentration of *trans*-resveratrol was Mikulov (0.16 mg/l). Highly significant difference was found between the sub-region Znojmo and Mělník that differ from the sub-region Mikulov. Higher concentrations of *trans*-resveratrol were found in wines from Litoměřice

Table 3. Values of *trans*-resveratrol, *trans*-piceid, *cis*-resveratrol and *cis*-piceid in Riesling wines according to individual localities in the Czech Republic (mg/l)

Locality	*Trans*-resveratrol	*Trans*-piceid	*Cis*-resveratrol	*Cis*-piceid
Syrovín	0.20 ± 0.01[abc]	0.08 ± 0.10	0.26 ± 0.02	0.19 ± 0.22
Archlebov	0.13 ± 0.12[ab]	0.14 ± 0.11	0.10 ± 0.06	0.27 ± 0.18
Žarošice	0.23 ± 0.08[abcd]	0.12 ± 0.08	0.20 ± 0.13	0.25 ± 0.14
Mikulov	0.14 ± 0.03[ab]	0.04 ± 0.02	0.07 ± 0.02	0.08 ± 0.04
Popice	0.17 ± 0.09[ab]	0.13 ± 0.05	0.12 ± 0.05	0.22 ± 0.08
Přítluky	0.25 ± 0.15[abcd]	0.11 ± 0.14	0.22 ± 0.23	0.28 ± 0.37
Hostěradice	0.73 ± 0.13[f]	0.26 ± 0.04	0.12 ± 0.00	0.14 ± 0.00
Stošíkovice	0.23 ± 0.21[abcd]	0.05 ± 0.01	0.11 ± 0.13	0.07 ± 0.02
Tasovice	0.36 ± 0.13[bcde]	0.16 ± 0.08	0.15 ± 0.05	0.20 ± 0.01
Znojmo	0.15 ± 0.07[ab]	0.09 ± 0.04	0.07 ± 0.05	0.13 ± 0.08
Podmolí	0.49 ± 0.15[e]	0.10 ± 0.06	0.21 ± 0.05	0.15 ± 0.11
Mělník	0.46 ± 0.19[de]	0.10 ± 0.05	0.09 ± 0.10	0.05 ± 0.06
Roudnice n/L.	0.36 ± 0.17[cde]	0.14 ± 0.11	0.25 ± 0.30	0.12 ± 0.05
Litoměřice	0.50 ± 0.11[ef]	0.17 ± 0.01	0.39 ± 0.18	0.30 ± 0.13
Velké Žernoseky	0.17 ± 0.07[abc]	0.15 ± 0.11	0.09 ± 0.06	0.21 ± 0.21
Most	0.12 ± 0.04[a]	0.05 ± 0.01	0.08 ± 0.07	0.07 ± 0.05

letters indicate significant differences determined by Tukey's test ($p < 0.01$)

and Mělník sub-regions, which fully corresponded with findings of Melzoch et al. (2001). They stated that the content of resveratrol in grapes most probably reflected the climatic conditions during the period of vegetation and fungal pressure which is higher in cold and humid conditions of the North Bohemia, Czech Republic. Another sub-region with high amount of *trans*-resveratrol was the Znojmo sub-region, which is characterized by very unequally distributed precipitation during the period of vegetation. More frequent period of drought can then have the influence on higher concentrations of *trans*-resveratrol in Riesling wines.

The differences in concentrations of phenolic compounds indicate that the accumulation of phenolic compounds in berries is highly influenced by terroir (Gambelli, Santaroni 2004; Rastija et al. 2009).

A similar conclusion was achieved in this study. *Trans*-resveratrol and its concentration in white wines from Riesling is considerably associated with the geographical origin of the vineyard or more precisely with the terroir where the wine grapes were cultivated. We succeeded in differentiation of wines according to wine-growing localities and sub-regions. The concentration of *trans*-resveratrol is therefore possible to use as a marker of wine-growing locality in produced wine when the sub-region of Mikulov is characterized by low concentrations of this compound and the sub-region of Znojmo and Mělník by high concentrations, respectively.

Table 4. Values of *trans*-resveratrol, *trans*-piceid, *cis*-resveratrol and *cis*-piceid in Riesling wines according to the individual sub-regions in the Czech Republic (mg/l)

Sub-region	Number of localities	*Trans*-resveratrol	*Trans*-piceid	*Cis*-resveratrol	*Cis*-piceid
Slovácko	3	0.20 ± 0.08[ab]	0.11 ± 0.08	0.20 ± 0.10	0.23 ± 0.16
Mikulov	2	0.16 ± 0.07[a]	0.10 ± 0.06	0.10 ± 0.05	0.17 ± 0.10
Znojmo	5	0.38 ± 0.24[b]	0.13 ± 0.08	0.13 ± 0.07	0.14 ± 0.07
Velké Pavlovice	1	0.25 ± 0.15[ab]	0.11 ± 0.14	0.22 ± 0.23	0.28 ± 0.31
Litoměřice	4	0.27 ± 0.18[ab]	0.12 ± 0.06	0.19 ± 0.19	0.17 ± 0.14
Mělník	1	0.46 ± 0.19[b]	0.10 ± 0.05	0.09 ± 0.10	0.05 ± 0.06

letters indicate statistically differences determined by Tukey's test ($p < 0.01$)

CONCLUSIONS

The study proved that in terms of quantity the most significant stilbene compound in wines of the Riesling cv. is *trans*-resveratrol. This compound was also the only one of all studied compounds that was possible to use for the wine differentiation according to the wine-growing locality and sub-region, i.e. according to the terroir in general. The highest concentration of *trans*-resveratrol was found in wines from Znojmo and Mělník sub-regions.

References

Adrian M., Jeandet P., Douillet-Breuil A.C., Tesson L., Bessis R., 2000. Stilbene content of mature *Vitis vinifera* berries in response to UV-C elicitation. Journal of Agriculture and Food Chemistry, *48*: 6103–6105.

Ali K., Maltese F., Hae Choi Y., Verpoorte R., 2009. Metabolic constituents of grapevine and grape-derived products. Phytochemistry Review, *9*: 357–378.

Arvanitoyannis I.S., 2010. Wine authenticity, traceability and safety monitoring. In: Reynolds A.G. (ed.), Managing Wine Quality. Vol. 1: Viticulture and Wine Quality. Cambridge, Woodheam Publishing: 218–270.

Atkin T., Johnson R., 2010. Appellation as an indicator of quality. International Journal of Wine Business Research, *22*: 42–61.

Bábíková P., Vrchotová N., Tříska J., Kyseláková M., 2008. Content of *trans*-resveratrol in leaves and berries of interspecific grapevine (*Vitis* sp.) varieties. Czech Journal of Food Sciences (Special Issue), *26*: S13–S17.

Bavaresco L., Fregoni M., 2001. Physiological role and molecular aspects of grapevine stilbenic compounds. In: Roubelakis-Angelakis K.S. (ed.), Molecular Biology and Biotechnology of the Grapevine. Dordrecht, Kluwer Academic Publisher: 153–182.

Bavaresco L., Pezzutto S., Gatti M., Mattivi F., 2007. Role of the variety and some environmental factors on grape stilbenes. Vitis, *46*: 57–61.

Cantos E., Espin J.C., Fernández M.J., Oliva J., Tomas-Barberan F.A., 2003. Post-harvest UV-C-irradiated grapes as a potential source for producing stilbene-enriched red wines. Journal of Agricultural and Food Chemistry, *51*: 1208–1214.

Careri M., Corradini C., Elviri L., Nicoletti I., Zagnoni I., 2004. Liquid chromatography-electrospray tandem mass spectrometry of *cis*-resveratrol and *trans*-resveratrol: development, validation, and application of the method to red wine, grape, and winemaking by products. Journal of Agricultural and Food Chemistry, *52*: 6868–6874.

Chafer A., Pascual-Marti M.C., Salvador A., Berna A., 2005. Supercritical fluid extraction and HPLC determination of relevant polyphenolic compounds in grape skin. Journal of Separation Science, *28*: 2050–2056.

Charlton A.J., Wrobel M.S., Stanimirova I., Daszykowski M., Grundy H.H., Walczak B., 2010. Multivariate discrimination of wines with respect to their grape varieties and vintages. European Food Research Technology.

Cho Y.J., Hong J.Y., Chun H.S., Lee S.K., Min H.Y., 2006. Ultrasonication-assisted extraction of resveratrol from grapes. Journal of Food Engineering, *77*: 725–730.

Creasy G.L., Creasy L.L., 2003. Grape-derived flavonoids and stilbenes. In: Sandler M., Pinder R. (ed.) Wine – A Scientific Exploration. London, Taylor and Francis: 199–227.

Dekič S., Milosavljevič S., Vajs Z., Jovič S., Petrovič A., Nikičevič N., Manojlovič V., Nedovič V., Tesevič V., 2008. *Trans*- and *cis*-resveratrol concentration in wines produced in Serbia. Journal of Serbian Chemical Society, *73*: 1027–1037.

de Villiers A., Majek P., Lynen F., Crouch A., Lauer H., Sandra O., 2005. Classification of South African red and white wines according to grape variety based on the non-coloured phenolic content. European Food Research Technology, *221*: 520–528.

Douglas D., Cliff M.A., Reynolds A.G., 2001. Canadian terroir: characterization of Riesling wines from the Niagara Peninsula. Food Research International, *34*: 559–563.

Faitová K., Hejtmánková A., Lachman J., Pivec V., Dudjak J., 2004. The contents of total polyphenolic compounds and *Trans*-resveratrol in white Riesling originated in the Czech Republic. Czech Journal of Food Science, *22*: 215–221.

Falchi M., Bertelli A., Scalzo R.L., Morassut M., Morelli R., Das S., Cui J.H., Das D.K., 2006. Comparison of cardioprotective abilities between the flesh and skin of grapes. Journal of Agricultural and Food Chemistry, *54*: 6613–6622.

Gambelli L., Santaroni G.P., 2004. Polyphenols content in some Italian red wines of different geographical origins. Journal of Food Composition and Analysis, *17*: 613–618.

Gambuti A., Strollo D., Ugliano M., Lecce L., Moio L., 2004. *Trans*-resveratrol, quercetin, (+)-catechin, and (–)-epicatechin content in South Italian monovarietal wines: Relationship with maceration time and marc pressing during winemaking. Journal of Agricultural and Food Chemistry, *52*: 5747–5751.

Goldberg D.M., Yan J., Ng E., Diamandis E.P., Kamumanchiri A., Soleas G.J., Waterhouse A.L., 1995. A global survey of *trans*-resveratrol concentrations in commercial wines. American Journal of Enology and Viticulture, *46*: 159–165.

Jeandet P., Bessis R., Maume B.F., Sbaghi M., 1993. Analysis of resveratrol in Burgundy wines. Journal of Wine Research, *4*: 79–85.

Jeandet P., Bessis R., Sbaghi M., Meunier P., Trollat P., 1995. Resveratrol content of wines of different ages: relationship with fungal disease pressure in the vineyard. American Journal of Enology and Viticulture, *46*: 1–4.

Jung K., Wallig M., Singletary K., 2006. Purple grape juice inhibits 7,12-dimethylbenz-α-anthracene anthracene (DMBA)-induced rat mammary tumorigenesis and *in* *vivo* DMBA-DNA adduct formation. Cancer Letters, *233*: 279–288.

La Torre G.L., Saitta M., Vilasi F., Pelicano T., Dugo G., 2006. Direct determination of phenolic compounds in Sicilian wines by liquid chromatography with PDA and MS detection. Food Chemistry, *94*: 640–650.

Li Z., Pan Q., Jin Z., Mu L., Duan C., 2010. Comparison on phenolic compounds in *Vitis vinifera* cv. Cabernet Sauvignon wines from five wine-growing regions in China. Food Chemistry, *125*: 77–83.

Melzoch K., Hanzlíková I., Filip V., Buckiová D., Šmidrkal J., 2001. Resveratrol in parts of vine and wine originating from Bohemian and Moravan vineyard regions. Agriculturae Conspectus Scientificus, *66*: 53–57.

Moreno A., Castro M., Falqué E., 2008. Evolution of *trans-* and *cis-*resveratrol content in red grapes (*Vitis vinifera* L. cv Mencía, Albarello and Merenzao) during ripening. European Food Research and Technology, *227*: 667–674.

Nikfardjam M.P., Rechner A., Patz C-D., Dietrich H., 1999. *Trans-*resveratrol content of German wines. Viticulture and Enological Science, *54*: 17–20.

Perrone G., Nicoletti I., Pascale M., De Rossi A., De Girolamo A., Visconti A., 2007. Positive correlation between high levels of ochratoxin A and resveratrol-related compounds in red wines. Journal of Agricultural and Food Chemistry, *55*: 6807–6812.

Pezet R., Pont V., Cuenat P., 1994. Method to determine resveratrol and pterostilbene in grape berries and wines using high-performance liquid chromatography with highly sensitive fluorometric detection. Journal of Chromatography, *663*: 191–197.

Rastija V., Srečnik G., Medic-Šaric M., 2009. Polyphenolic composition of Croatian wines with different geographical origins. Food Chemistry, *115*: 54–60.

Rentzsch M., Wilkens A., Winterhalter P., 2009. Non-flavonoid phenolic compounds. In: Moreno-Arribas M.V., Polo M.C. (eds), Wine Chemistry and Biochemistry. New York, Springer, 509–527.

Reynolds A.G., Senchuk I., De Savigny C., 2007. Use of GPS and GIS for elucidation of the basis for terroir. Spatial variation in an Ontario Riesling vineyard. American Journal of Enology and Viticulture, *58*: 145–162.

Reynolds A.G., De Savigny C., Willwertht J., 2010a. Riesling terroir in Ontario vineyards. The roles of soil texture, vine size and vine water status. Progrès Agricole et Viticole, *127*: 212–222.

Reynolds A.G., Marciniak M., Brown R., Tremblay L., Baissas L., 2010b. Using GPS, GIS and airborne imaging to understand Niagara terroir. Progrès Agricole et Viticole, *127*: 259–274.

Rodriguez-Delgado M.A., González G., Pérez-Trujillo J.P., Garcia-Montelongo F.J., 2002. *Trans-*resveratrol in wines from the Canary Islands (Spain). Analysis by high performance liquid chromatography. Food Chemistry, *76*: 371–375.

Rodriguez-Vaquero M.J.; Alberto M.R., Manca-De-Nadra M.C., 2007. Antibacterial effect of phenolic compounds from different wines. Food Control, *18*: 93–101.

Romero-Pérez A.I., Lamuela-Raventós R.M., Waterhouse A.L., De La Torre-Boronat M.C., 1996. Levels of *cis-* and *trans-*resveratrol and their Glucosides in white and rosé *Vitis vinifera* wines from Spain. Journal of Agricultural and Food Chemistry, *44*: 2124–2128.

Seguin G., 1986. "Terroirs" and pedology of vinegrowing. Experientia, *42*: 861–873.

Stockley C.S., Hoj P.B., 2005. Better wine for better health: Fact or fiction? Australian Journal of Grape and Wine Research, *11*: 127–138.

Šmidrkal J., Filip V., Melzoch K., Hanzlíková I., Buckiová D., Kříša B., 2001. Resveratrol. Chemické listy, *95*: 602–609.

van Leeuwen C., Roby J.-P., Pernet D., Bois B., 2010. Methodology of soil-based zoning for viticultural terroirs. Bulletin de l'O.I.V., *83*: 13–29.

Vrhovsek U., Vanzo A., Nemanič J., 2002. Effect of red wine maceration techniques on oligomeric and polymeric proantho-cyanidins in wine, cv. Blaufränkisch. Vitis, *41*: 47–51.

Waffo-Teguo P., Krisa S., Richard T., Mérillon J.-M., 2008. Grapevine stilbenes and their biological effects. In: Ramawat K.G., Mérillon J.M. (ed.), Bioactive Molecules and Medicinal Plants. Berlin, Springer-Verlag: 25–54.

Waterhouse A.L., 2002. Wine phenolics. Annals of the New York Academy of Sciences. *957*: 21–36.

Willwerth J.J., Reynolds A.G., Leeschaeve L., 2010. Terroir factors: Their impact in the vineyard and on the sensory profiles of Riesling wines. Progrès Agricole et Viticole, *127*: 159–168.

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