<table>
<thead>
<tr>
<th>Opera suspiciune (OS)</th>
<th>Opera autentică (OA)</th>
</tr>
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<tbody>
<tr>
<td><strong>Suspicious work</strong></td>
<td><strong>Authentic work</strong></td>
</tr>
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**Incidența minimă a suspiciunii / Minimum incidence of suspicion**

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Determination of Organic Acids in White Wines by RP-HPLC

Mira Kordiš-Krapež1*, Veronika Abram2, Milica Kač2 and Stanka Ferjančič2

1 BIA, d.o.o., Teslova 30, SI-1000 Ljubljana, Slovenia
2 Department of Food Science and Technology, Biotechnical Faculty, University of Ljubljana, Jamnikarjeva 101, SI-1111 Ljubljana, Slovenia

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Summary
The chromatographic conditions for the optimal separation of tartaric, malic and citric acids on a LiChrosorb RP-18 column (10 μm, 25 cm x 4.0 mm i.d.) at 210 nm were determined. The optimized RP-HPLC method (mobile phase: c(H₃PO₄) = 6 · 10⁻³ mol/L, pH = 2.1, flow rate 1.0 mL/min) was validated. Calibration curves were linear for all three acids in the concentration range tested; r² was better than 0.999. RSDs for tartaric and malic acids were within ± 2 %, and for citric acid ± 10.4 %. The average relative error for tartaric acid was 3.2 %, for malic acid 2.5 % and for citric acid 6.0 %. Ethanol caused an insignificant negative response at tR = 5.69 min, whereas glucose and fructose eluted in the void volume. According to the validation results, and from analysis of wine samples, the described HPLC method was found adequate for routine determination of tartaric and malic acids and to some extent also of citric acid in dry, semi-dry, semi-sweet and sweet white wines.

Key words: organic acids, RP-HPLC analysis, white wine

Introduction
Quantitative determination of organic acids can be an additional support to sensorial and microbiological quality assessment of wines (1). The most widely used HPLC methods for their determination are ion exchange, (2,3) and ion exclusion (4) HPLC techniques. Today, the reversed phase HPLC methods are very popular in general (5), but not for organic acids determination in wine and must samples.

Our aim was to introduce LiChrosorb RP-18 as a stationary phase for routine and inexpensive HPLC determination of tartaric and malic acids in wines. These two acids are present in grapes in much higher concentrations than other acids. Their ratio is also an indicator of vintage quality (6). We found that with RP-HPLC on LiChrosorb RP-18 six organic acids (i.e. galacturonic, tartaric, malic, lactic, succinic and citric acids) can be separated. The chromatographic conditions for the optimal separation of the organic acids were established, and the method was validated. The results of selectivity, linearity, precision and accuracy are presented here. Due to some interferences, the RP-HPLC method described was found adequate only for the routine determination of tartaric and malic acids and to some extent also of citric acid in dry, semi-dry, semi-sweet and sweet white wines. The method was used to determine tartaric and malic acid concentrations in 28 white wine samples (vintage 1995) from three major wine-producing regions in Slovenia. Wine samples were of different quality and also varied in ethanol and sugar contents.

* Corresponding author; Fax: ++386 (0)1 4264 591; E-mail: mira.kordis@tp-lj.si
Materials and Methods

Chemicals

All acids and reagents used were of analytical grade. Organic acids (p.a.) were from Merck, Germany.

Solvent

In preparation of wine samples and standard solutions a mixture of 96% ethanol and double distilled water (volume ratio 10/90) was used, which is referred to as the solvent. Prior to use, the solvent was sonicated for 5 minutes in an ultrasonic bath to remove air bubbles.

Standard solutions of organic acids

All organic acids used for standards were dissolved in the solvent to simulate the matrix effect of wine samples. The concentrations of organic acids varied from 0.5 to 10.0 g/L for tartaric acid; 0.2 to 15.0 g/L for malic acid; 0.1 to 5.4 g/L for lactic acid, and 0.05 to 1.0 g/L for citric acid. The prepared standard solutions of organic acids were stored at 4 °C.

Standard solutions of sugars

Two standard sugar solutions were prepared. The first one contained $c_{103}(\text{glucose}) = 100$ g/L, and the second one $c_{103}(\text{fructose}) = 100$ g/L of the solvent.

Wine samples

The samples were provided from local wineries. Samples of 28 Slovenian white wines of vintage 1995 (see Table 4) were tested. They differed in quality, sugar concentration and provenience. Ethanol volume fraction varied from 10.1 to 12.6 %, according to the producers. An aliquot of wine sample was diluted (volume ratio 1/1) with solvent and 20 $c_{109}$L of the obtained solution were injected. Before injection, all standards and sample solutions were filtered through Sartorius RC15 membrane filter units.

Spiked wine samples

For precision and accuracy validation, wine samples were spiked with organic acids to such an amount that the final concentration of the added acid varied from 1 to 3 g/L for tartaric and malic acids, and from 0.09 to 0.27 g/L for citric acid. Organic acid standards were accurately weighed in 50 mL volumetric flasks and dissolved in about 10 mL of the solvent. Then 25.0 mL of wine sample was added and the solution obtained was further diluted to 50 mL with the solvent.

HPLC system

This comprised an X-act 4-channel degassing unit (Jour Research, Sweden), a Maxi Star, K1000 HPLC pump (Knauer, Germany), a Marathon-XT autosampler (Spark-Holland, Holland), a UV/VIS detector (Knauer, Germany), a K-2301 RI detector (Knauer, Germany) and a ValueChrom data acquisition system (Bio-Rad, USA).

Chromatographic conditions for determination of organic acids

A LiChrosorb RP-18 column (10 $c_{109}$m, 25 cm x 4.0 mm i.d.), (Merck, Germany), with an injection volume of 20 $c_{106}$L, wavelength 210 nm, and a mobile phase as below, flow rate 1.0 mL/min was employed.

For optimization of the separation of organic acids, aqueous solutions of $H_3PO_4$ in three different concentrations were tested: mobile phase 1 = $3.0 \cdot 10^{-4}$ mol/L (pH = 3.0), mobile phase 2 = $1.5 \cdot 10^{-3}$ mol/L (pH = 2.5), mobile phase 3 = $6 \cdot 10^{-3}$ mol/L (pH = 2.1).

Chromatographic conditions for glucose and fructose determination

Before determination of organic acids, glucose and fructose were determined on a Bio-Rad Aminex HPLC-87C (30 cm x 7.8 mm i.d.) column at 80 °C using an RI detector. Double distilled water was used as the mobile phase, with an injection volume of 20 $c_{106}$L, and a flow rate of 0.6 mL/min (7).

Results

Influence of pH of the mobile phase

Separation of the organic acids on an HPLC LiChrosorb RP-18 (10 $c_{106}$m, 25 cm x 4.0 mm i.d.) column was tested with three $H_3PO_4$ solutions. Mobile phase 3 $c(H_3PO_4) = 6 \cdot 10^{-3}$ mol/L was the best mobile phase for HPLC separation of the organic acids tested as shown for 4 of them in Fig. 1. Although the pH of the mobile phase was 2.1, no column deterioration was observed even after prolonged use.

Selectivity of the method

Under the conditions described galacturonic, tartaric, malic, lactic, succinic and citric acids could be separated on a LiChrosorb RP-18 (10 $c_{106}$m, 25 cm x 4.0 mm i.d.) column (Fig. 2). The peaks of all acids were symmetrical and well separated, but the chromatogram in Fig. 2 shows 7 peaks. It was found that two peaks ($t_R = 9.35$ and 10.63 min) belong to succinic acid. We cannot
explain the reason for such behaviour. Succinic acid has $pK_1 = 4.16$ and $pK_2 = 5.61$ in aqueous solution, but these do not explain the occurrence of two peaks in a mobile phase with $pH = 2.1$. It is unclear why two peaks appear only in the case of succinic and not in the case of any other polycarboxylic acid. When the same standard solution of succinic acid was injected on a Bio-Rad Aminex HPX-87H column, only one peak was observed (unpublished results).

With the optimal mobile phase we were able to separate 6 organic acids (Fig. 2), but when validating the method, we found it suitable only for the 3 most representative (tartaric, malic and citric) acids in white wines.

Possible interference of ethanol, glucose and fructose on the determination of the acids was checked by separate injection of 20 $\mu$L of ethanol, glucose and fructose standard solutions. Both sugars were dissolved in ethanol. Ethanol did not interfere with the determination of organic acids. Its elution at 5.69 min caused a very small, but negative response under the chromatographic conditions described. Glucose and fructose eluted in the void volume with $t_R = 3.10$ min.

The influence of shikimic and acetic acids on the determination of the main organic acids in wine was checked too. When a mixture of shikimic, lactic and acetic acids was injected, the separation of shikimic acid...
from lactic acid was poor (Fig. 3). The resolution between shikimic and lactic acid was only 0.5, and the resolution between lactic and acetic acid was 1.3. Shikimic acid eluted at 5.05 min under the chromatographic conditions used. Usually, the concentration of shikimic acid in wines is low, but this acid has a much higher extinction coefficient than the other organic acids present in wine. Therefore, this RP-HPLC method is not selective for the determination of lactic acid.

**Linearity of the method**

The linearity of the method was validated at six to eight concentrations of each acid (tartaric, malic and citric acids). The concentrations of the standard solutions of organic acids were chosen in such a way that the whole expected concentration range of each acid in the samples was covered. A calibration curve for each organic acid was constructed by linear regression of the observed average peak area versus concentration. The coefficients of the regression curves (the slope and the intercept on the y axis) and the squares of the correlation coefficients were calculated by the least squares method. Calibration curves were linear for all the organic acids investigated (Table 1).

**Precision of the method**

The precision of the method was determined by consecutive injections of blank wine samples and wine samples spiked with different concentrations of tartaric, malic and citric acids. For each concentration, the average area of the detector response, the standard deviation and the relative standard deviation were calculated (Table 2).

The precision validation indicated that this HPLC method is suitable for tartaric and malic acid determination in white wines under the chromatographic conditions described (Table 2). The precision of the citric acid determination, on the contrary, shows that this method is not suitable for its quantitative determination in white wines. The main reason for such low precision of the citric acid determination is the low concentration of this acid in wines. Citric acid in wine can be quantified by this RP-HPLC method with a precision of only about 10 %.

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**Table 1. Coefficients of the regression curve and the square of the correlation coefficient for each organic acid; HPLC analysis:**

<table>
<thead>
<tr>
<th>Organic acid</th>
<th>γ(acid)range (acid)</th>
<th>Slope</th>
<th>Intercept</th>
<th>$r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tartaric</td>
<td>0.500– 7.508 g/L</td>
<td>236.35</td>
<td>14.074</td>
<td>0.9998</td>
</tr>
<tr>
<td>Malic</td>
<td>0.200–15.000 g/L</td>
<td>128.62</td>
<td>4.621</td>
<td>0.9998</td>
</tr>
<tr>
<td>Citric</td>
<td>0.049–0.987 g/L</td>
<td>1685.6</td>
<td>–3.124</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

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**Table 2. Precision of tartaric, malic and citric acid determination in wine samples on LiChrosorb RP-18 column; chromatographic conditions as in Table 1**

<table>
<thead>
<tr>
<th></th>
<th>γ(spiked) (g/L)</th>
<th>γ(total) (g/L)</th>
<th>RSD (N=6)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tartaric</td>
<td>0.0 1.9</td>
<td>1.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.0 2.9</td>
<td>0.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.0 3.9</td>
<td>0.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.0 4.9</td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>average 0.51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malic</td>
<td>0.0 2.9</td>
<td>2.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.0 3.9</td>
<td>1.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.0 4.9</td>
<td>0.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.0 5.9</td>
<td>0.37</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>average 1.03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Citric</td>
<td>0.0 0.24</td>
<td>15.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.09 0.42</td>
<td>7.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.18 0.51</td>
<td>6.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.27 average 10.41</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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**Table 3. Accuracy of tartaric, malic and citric acid determination in wine samples on LiChrosorb RP-18 column; chromatographic conditions as in Table 1**

<table>
<thead>
<tr>
<th></th>
<th>γ(spiked) (g/L)</th>
<th>γ(total) (g/L)</th>
<th>Average RE (N=6)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tartaric</td>
<td>1.017 0.966</td>
<td>–5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.012 1.961</td>
<td>–2.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.019 2.954</td>
<td>–2.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>average 0.51</td>
<td>–3.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malic</td>
<td>1.009 0.988</td>
<td>–2.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.013 1.967</td>
<td>–2.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.022 2.930</td>
<td>–3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>average 1.03</td>
<td>–2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Citric</td>
<td>0.093 0.088</td>
<td>–5.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.185 0.182</td>
<td>–1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.275 0.245</td>
<td>–10.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>average 10.41</td>
<td>–6.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The accuracy of the method was measured as the agreement between the measured and the true value (found concentration and added concentration). Since for wine samples, the true value was not known, an approximation was obtained based on spiking a wine sample with known amounts of tartaric, malic and citric acids. A wine sample was spiked with three different concentrations of tartaric, malic and citric acids (added concentrations). The found concentration, $c_{\text{found}}$, of each acid at each concentration was calculated by the method of external standards as follows:

$$c_{\text{found}} = \frac{(A_{\text{spiked}} - A_{\text{blank}}) \cdot c_{\text{std}}}{A_{\text{std}}}$$

where $A_{\text{spiked}}$ is the detector’s response of spiked sample, $A_{\text{blank}}$ is the detector’s response of blank sample, $c_{\text{std}}$ is the concentration of standard solution, g/L, and $A_{\text{std}}$ is the detector’s response of standard.

By comparing the found concentrations to the added concentrations, the relative error (RE, %) was calculated for the determination of each acid (Table 3).

Similarly as in the case of precision, the best accuracy was found for tartaric and malic acids, the average relative errors being 3.2 % and 2.5 %, respectively, while the average relative error in the determination of citric acid was 6.0 %.

Wine analysis

The described HPLC method was finally used on 28 white wines (Fig. 4) from different wine-producing regions in Slovenia (different sugar contents, all 1995 vintage). The results of the glucose and fructose determinations (analyses were performed as described under Materials and Methods), as well as those of tartaric and malic acid determinations are presented in Table 4.

Conclusions

The described RP-HPLC method using LiChrosorb RP-18 (10 μm, 25 cm x 4.0 mm i.d.) with $c(H_3PO_4) = 6 \cdot 10^{-3}$ mol/L (pH=2.1) as mobile phase and UV detection at 210 nm is fast, all acids eluting in less than 9 min. When analysing different types of white wine no additional unknown interference appeared. According
to the validation results and from the analysis of different wine samples, the HPLC method described was found adequate for routine determination of tartaric and malic acids in dry, semi-dry, semi-sweet and sweet white wines. To a limited extent the method can also be considered adequate for routine determination of citric acid in various white wines.

The results of the validation were compared to the results of other authors (Table 5, 1,2). The linearity of the HPLC methods compared is similar and adequate. Accuracy expressed as recovery shows that on LiChrosorb RP-18 a lower amount of the acids is determined, but the found values are still within the reliability interval of the methods to which our results are compared. The precision of our method for tartaric and malic acid determination is better or comparable to the precision of other HPLC method, while the precision for the citric acid is rather worse.

The main disadvantage of the method presented is the fact that not all organic acids of potential interest can be determined and that succinic acid has two peaks.

On the other hand, it offers good routine quantitative determination of the two most important organic acids in white wines, as well as fast and simple isocratic separation on an inexpensive stationary phase with an unsophisticated HPLC system.

### References

7. Guide to Aminex HPLC Columns for Food and Beverage Analysis, Bio-Rad, Chemical Division, Richmond, CA, USA.