HUNGARIAN UNIVERSITY OF AGRICULTURE AND LIFE SCIENCES

INVESTIGATION OF THE CONCENTRATION OF 1,1,6-TRIMETHYL-1,2-DIHYDRONAPHTHALENE (TDN) IN DOMESTIC AND FOREIGN RHINE RIESLING, ITALIAN RIESLING AND KÉKNYELŰ WINES

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Thesis of PhD dissertation

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1. BACKGROUND AND THE OBJECTIVES OF THE RESEARCH

1.1. Backgrounds

As in other wine-producing regions, climate change is negatively affecting the fresh, fruity character of wines also in Hungary. Not only should higher alcohol and lower acidity be expected, but also changes in the aroma composition. One such aroma is 1,1,6-trimethyl-1,2-dihydronaphthalene (TDN), a compound derived from the carotenoids in grapes, which gives the so-called kerosene character to Rhine Riesling wines. As a result of climate change, the concentration of TDN in Rhine Riesling wines is expected to increase from the increased amount of carotenoids produced in grapes, and should also be expected to be present in wines of other grape varieties. Therefore, I investigated, for the first time in Hungary, the development of the amount of TDN causing kerosene taste sensation in Hungarian wines (mainly Rhine Riesling, Italian Riesling and Kéknyelű).

In the case of aged Rhine Riesling wines, the kerosene taste sensation is accepted by consumers, but its presence in young wines is considered a defect. It is also qualified a defect in the Italian Riesling and Kéknyelű wines I have tested.

1.2. Objectives

The focus of my research was to determine whether the development of TDN and the associated sensory changes in domestic Rhine Riesling wines are significant. As climate change affects all grape varieties, and therefore the wines made from them, I thought it was important to investigate, whether we should also expect the presence of a kerosene/petrol flavour component in wines made from Italian Riesling, another Riesling variety with a significantly larger area under cultivation in our country compared to the Rhine Riesling grape. This is particularly interesting given that the negative effects of climate change are also being felt in our country. For comparison purposes, I chose the Kéknyelű grape variety, as the wines of this variety are generally neutral in character, lacking in aroma and flavour and do not have the aroma of kerosene.

Based on the above, I set the following goals for my PhD thesis

1. My primary objective was to conduct a series of mapping studies to determine the extent to which the kerosene character is present in the Hungarian Rhine Riesling and Italian Riesling wines, and the concentration range in which TDN can be measured. I used the gas chromatography (GC-FID) method to quantify that. I validated the method and performed GC-MS confirmation tests on some wines.

2. A further aim of my PhD thesis was to investigate whether there is a significant difference between the TDN production potential of the two Riesling varieties popular in Hungary, Italian Riesling and Rhine Riesling, and to determine which grape variety has a higher average concentration of TDN in its wine.

3. My aim was to investigate whether the Kéknyelű Hungarian grape variety is likely to exhibit a petrol-like character in its wines due to climate change.

4. My aim was to investigate the correlation between measured TDN concentrations and sensory assessment scores as a

function of alcohol concentration. For that, I conducted a sensory analysis with the help of a professional tasting committee and compared the results with the measured TDN concentrations.

5. I also had the opportunity to measure the TDN content of foreign Rhine Riesling wines, so I aimed to compare these wines with domestic Rhine Riesling wines. I investigated whether there is a significant difference in the concentration of TDN between wines from international wine regions and wines from Rhine Riesling grapes grown in Hungarian areas.

6. The aim of my PhD thesis was to study the effect of different closure methods on the increase of TDN in bottled wines. The wines tested were filled into bottles sealed with cork stoppers and screw caps. I compared whether there is a difference in the change in TDN concentration as a function of time for the two modes of capping.

7. In my PhD thesis I had the opportunity to determine the concentration of TDN in Rhine Riesling wines from the same winery of different vintages. My aim was to investigate the effect of ageing time on the amount of TDN content.

8. In my thesis I also studied the effect of vintage. I wanted to find out whether the increasing irradiation associated with climate change has an effect on the concentration of TDN in wines.

2. MATERIALS AND METHODS

2.1. Samples

I performed the analytical examination of 208 bottles of wine samples. Of those, 170 were bottles of commercial wine purchased in Hungary and 38 were foreign bottles of Rhine Riesling wine from different wine regions. The domestic samples were Italian Riesling (88 bottles), Rhine Riesling (54 bottles) and Kéknyelű (28 bottles) from different vintages (2006-2021) and different wineries.

I investigated the effect of bottle closure on the change in TDN concentration during storage for domestic Italian Riesling and Rhine Riesling wines. The domestic wines I examined were partly sealed with cork stoppers and partly with screw caps.

2.2. Methods

2.2.1. Analysis of basic parameters

The basic analysis (alcohol content (v/v%), reducing sugars, titratable acidity, and pH) of the domestic wine samples analysed was conducted using the following methods:

- The quantity of ethanol, reducing sugars and the titratable acid content was determined using a FOSS WineScan Fourier transform infrared spectroscopy (FT-IR) instrument.
- I measured the pH of the wines using a pH meter (OIV-MA-AS313-15:R2012) (OIV, 2023).

2.2.2. Instrumental analysis

At the research laboratory of the Viticulture Department of MATE Institute of Viticulture and Oenology, I had at my disposal a GC-FID instrument equipped with an automatic sample preparation unit, so I used this instrument to determine the TDN content of the wines. For some wines I also had the opportunity to perform confirmatory GC-MS measurements at the NÉBIH ÉLI National Reference Laboratory for Toxicology.

2.2.5. Sensory analysis

The tasting committee scored the 170 bottles of domestic wine by variety on a targeted TDN-only scale of 1-5 points according to the general rules of wine assessment.

2.2.6. Statistical analysis

The measurement results were statistically evaluated using Microsoft Excel (version 18.2106.12410.0, license: Microsoft Corporation). The results of the analytical measurement were evaluated with the one-factor variance analysis at 95% (p=0.05) significance level. The results thus obtained were refined using the Tukey-Kramer test.

The results of the sensory analyses were obtained by calculating the Spearman rho correlation coefficient.

2.3. Experiments

2.3.1. Investigation of the effect of bottle closure

The TDN of the wines was measured immediately after opening the bottle, then again after 6 months, then at the end of the 12th, 18th and 24th month. The wines were stored in their own bottles, sealed with their original sealing elements, until re-measuring. All the wines included in the study were stored in the same room, upright, protected from sunlight, at an average temperature of 22°C until the repeated analysis. Since the external conditions were the same, except for the way the wines were sealed, I was able to investigate whether the presence of air made a difference to the amount of TDN produced, or whether the way the wine was sealed made a detectable difference.

3. RESULTS AND DISCUSSION

Based on the average results of the basic analysis of the domestic wines tested, it can be said that the wines tested meet the requirements of an average wine free of wine defects. The average alcohol content of wines has increased by 1-2 v/v% over the last 20-25 years and this trend can also be observed in the domestic wines I have studied. The wide variation in residual sugar is due to the fact that the wine samples analysed included both dry and sweet wines. In addition to the alcohol content, the titratable acid content is also increasing due to climate change, a trend that is also clearly visible in the wines I have studied.

3.1. Analysis of the TDN content of domestic wines

Of the wines from the various producers, 62 bottles came from the Balaton wine region, 27 bottles from the Pannon wine region, 25 bottles from the Upper Hungary wine region, 27 bottles from the Upper Pannon wine region and 29 bottles from the Danube wine region.

I measured and analysed the TDN concentrations of the three domestic wine varieties I studied (Italian Riesling, Rhine Riesling and Kéknyelű). The wines were from the vintage years 2006-2021. I measured TDN concentrations using the HS-SPME-GC-FID technique every 6 months for 2 years. The first measurement was taken immediately after opening the bottle (1st series of measurement), and then after the 6th (2nd series of measurement), 12th (3rd series of measurement), 18th and 24th months. By month 12, the concentration of TDN in the wines had dropped to the detection limit of the gas chromatography method and remained stable at months 18 and 24.

Different thresholds for TDN have been established in the technical literature. Based on the thresholds they set, I evaluated the wines I tested based on their TDN concentration. Directly at bottle opening, the TDN content of 43 of the 170 bottles of domestic wine (25% of all domestic wines tested) reached the detection threshold, 21 bottles (12.5% of all domestic wines tested) reached the recognition threshold and the TDN concentration of no bottles of wine, regardless of variety, reached the rejection threshold.

3.1.1. TDN concentration of Italian Riesling wines

The Italian Riesling wines tested were from the 2010 - 2021 vintage. TDN concentrations were in the range 0.3 - 7.0 µg/l at the time of the first series of measurements (Fig. 1).

In the 88 bottles of Italian Riesling tested, an increase in TDN concentrations was observed after 6 months of storage after opening, with 11 bottles showing a significant increase at the 95% (p=0.05) probability level. This increase was nearly 30 times for wine batch 7, but there was also a significant 18-fold increase for wine batch 4. The highest concentration (36.3 µg/L) was measured in the second series of measurements, which was in wine from a 2018, from the wine region in Upper Hungary, batch 8 in the figure. The largest increase in TDN concentration occurred in a wine batch from the Balaton wine region, also from 2018 (batch 7 in the figure). At the time of the first measurement, the concentration of TDN was not detectable by the analytical method I used, but by the time of the second measurement, the wine contained 32.2 µg/l TDN. At the time of the second set of measurements, 44 wine samples had TDN content above the detection threshold and 21 bottle samples above the recognition threshold, representing 23% of all Italian Riesling wine samples tested.

The TDN content of none of the wines crossed the rejection threshold.

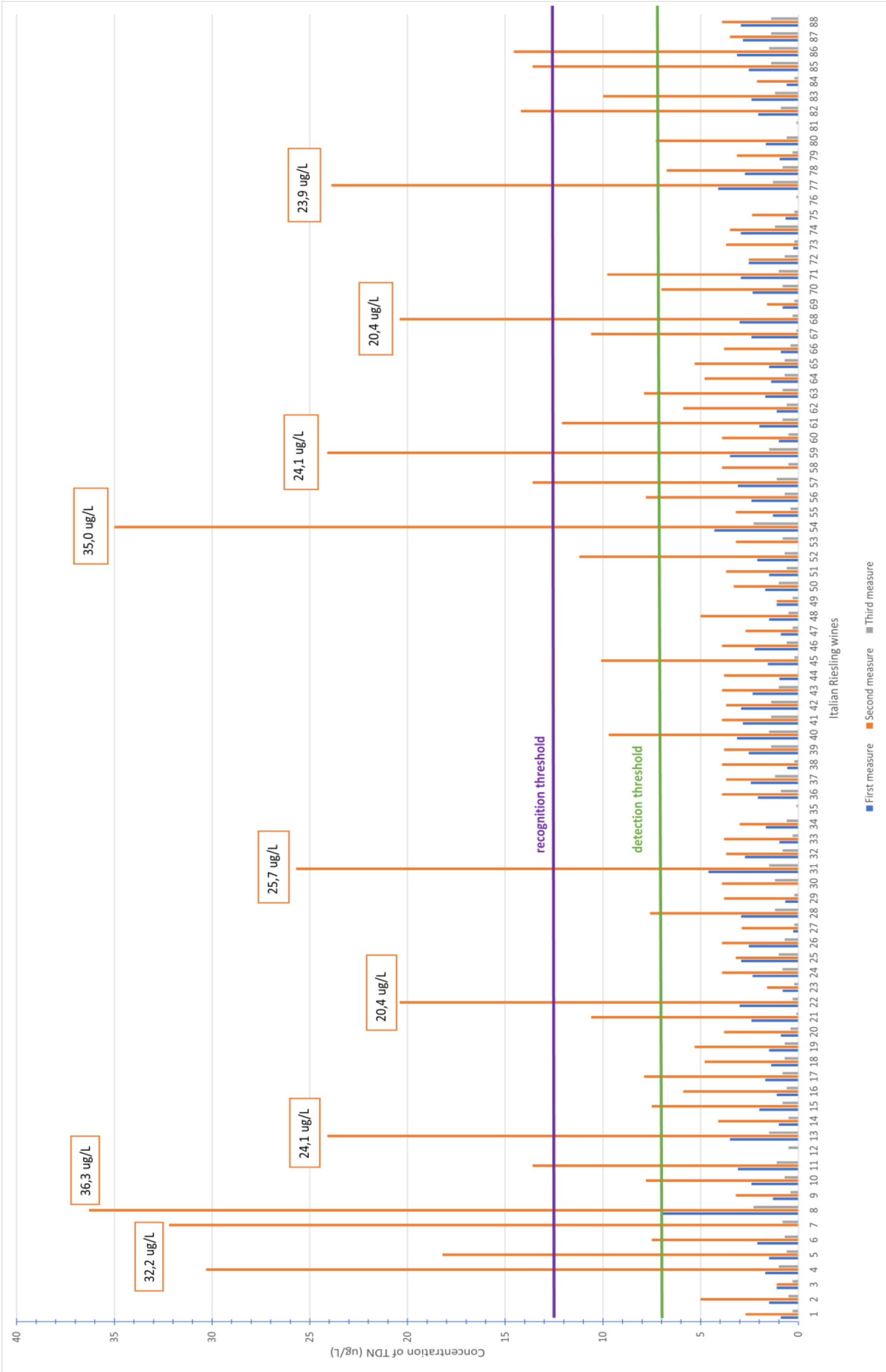

Fig. 1. Evolution of the TDN concentration of Italian Riesling wines at the moment of opening the bottle (blue), after 6 months (orange), and in the 12th month (grey).

3.1.2. TDN concentration of Rhine Riesling wines

The Rhine Riesling wines tested were from the 2010 - 2020 vintage. TDN concentrations were in the range 0.6 - 63.5 μg/l at the time of the first series of measurements (Fig. 2).

For the 54 bottles of Rhine Riesling wine tested, an increase in TDN concentration was generally observed after 6 months. Two wine samples show a significant (almost sixfold) increase in TDN content at 95% ($p=0.05$) probability level. I observed a decrease in TDN concentration in 3 cases. Nine wine batches had TDN concentrations above the consumer rejection threshold at the time of the second measurement. This represents 17% of all Rhine Riesling wines analysed.

At the time of the first measurement, 41% of the Rhine Riesling wines exceeded the recognition threshold, and by the time of the second measurement, 65% of all Rhine Riesling wines tested exceeded the recognition threshold.

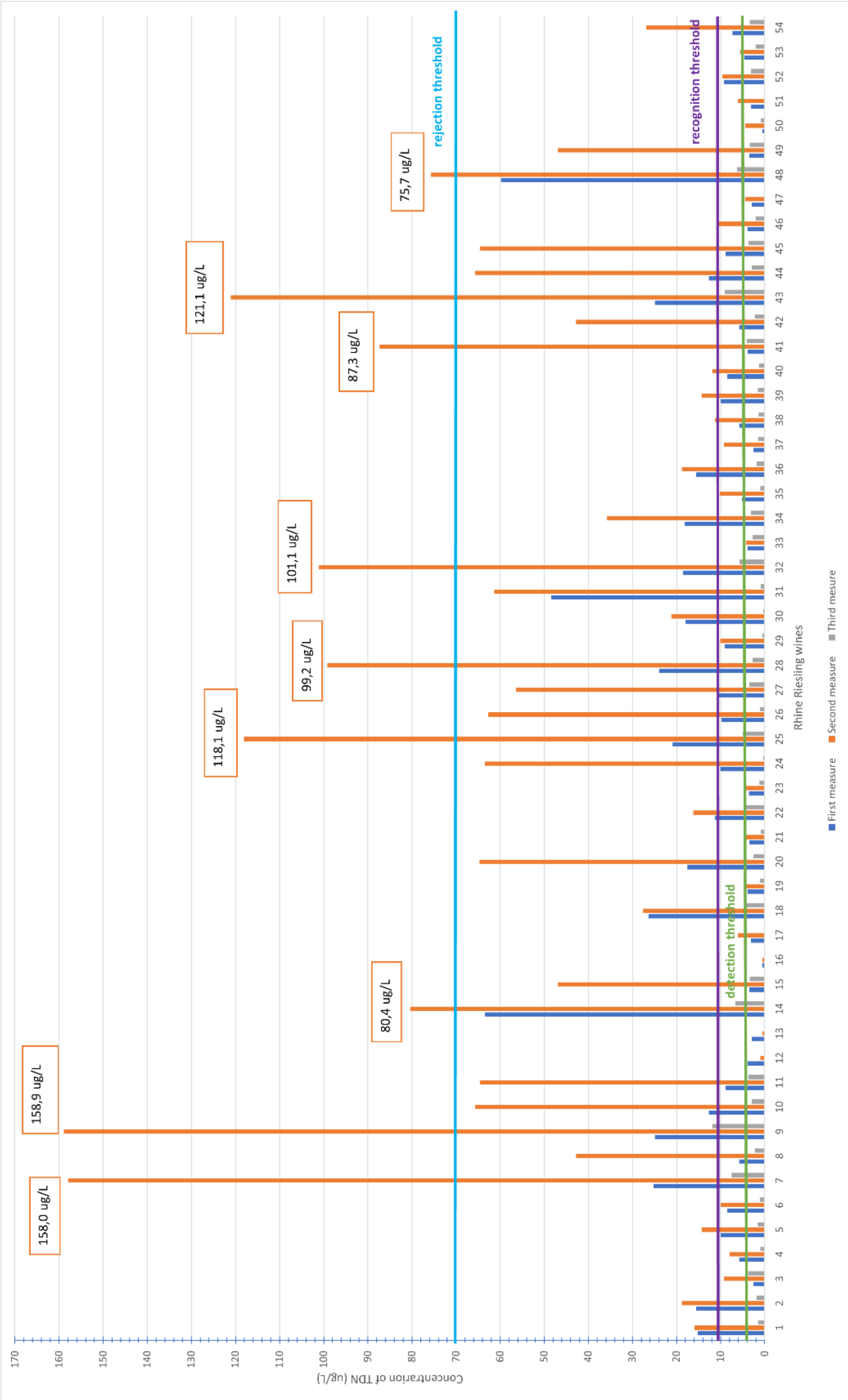

Fig. 2. Evolution of the TDN concentration of Rhine Riesling wines at the moment of opening the bottle (blue), after 6 months (orange), and in the 12th month (grey).

3.1.3. TDN concentration of Kéknyelű wines

The Kéknyelű wines from the Balaton wine region were from the vintage years 2006 - 2020. TDN concentrations were in the range 0.3 - 9.1 µg/l at the time of the first series of measurements I measured the highest outstanding TDN concentration of 9.1 µg/l in a 2007 vintage wine (Fig. 3).

For Kéknyelű wines, I have found that this variety is not prone to TDN formation. Out of a total of 28 bottles of wine produced from Kéknyelű grapes, only two samples had TDN concentrations above the detection threshold immediately at bottle opening: sample 2 from the 2006 vintage (5.2 µg/l TDN) and sample 3 from the 2007 vintage (9.1 µg/l TDN). Based on my measurements, the results of the second series of measurements did not clearly show an increase in TDN concentration: in some batches it increased significantly and in some batches it decreased significantly.

The TDN concentration (7.6 µg/l) of the wine batch 5 of the 2012 vintage was already close to the recognition threshold at the time of the second measurement. The concentration of TDN in batch 23 (5.3 µg/l) also increased significantly. The increase in TDN concentration in both wines is significant at 95% (p=0.05) probability level. The recognition threshold concentration was not reached by the TDN concentration of any of the Kéknyelű wine samples tested during the whole series of measurements. The average low TDN concentrations in Kéknyelű wines showed a decrease in 61% of the samples.

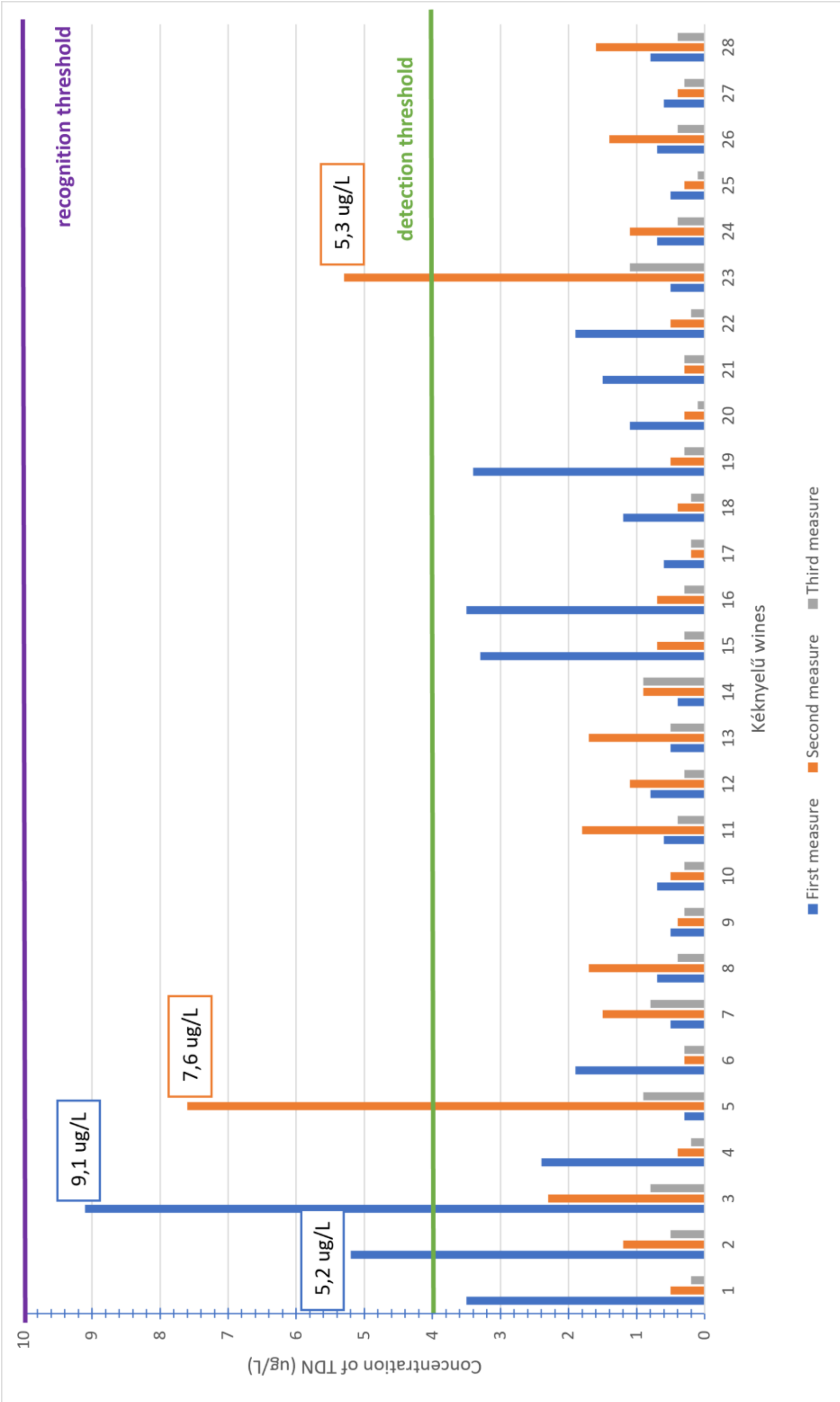

Fig. 3. Evolution of the TDN concentration of Kéknyelű wines at the moment of opening the bottle (blue), after 6 months (orange), and in the 12th month (grey).

3.2. TDN concentrations in a variety comparison

Fig. 4 shows TDN concentrations in a variety comparison. It can be observed that among the three wine varieties, the Rhine Riesling has a significantly higher tendency to form TDN compared to the other two varieties The TDN concentrations measured in the first series of measurements already exceed those measured in the other two varieties of wine. During storage, the concentration of TDN in Italian Riesling wines also increases, but the increase is greater in Rhine Riesling wines.

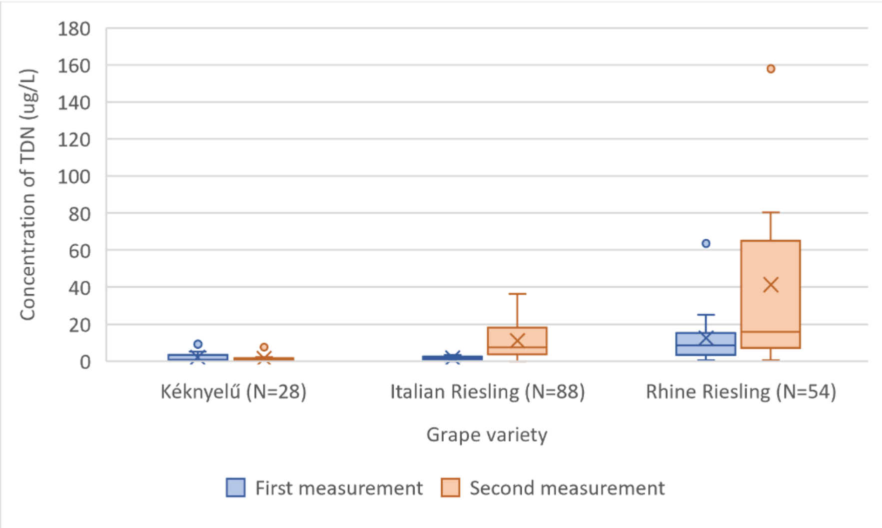

Fig. 4. Boxplot showing TDN concentrations compared by type at bottle opening (first measures) and 6 months later (second measures) (°outliers)

Analysing the results by one-factor analysis of variance, it can be concluded that there are significant differences between the TDN production of the varieties at 95% significance level ($p=0.05$) based on the measured TDN concentrations.

Examining that further, applying the Tukey-Kramer test, it can be concluded that the difference in TDN concentrations between Italian Riesling and Rhine Riesling wines is statistically significant. The same conclusion can be drawn when comparing the TDN concentrations of Rhine Riesling and Kéknyelű wines. However, for Italian Riesling and Kéknyelű wines, no significant difference between the TDN production of the varieties could be detected at the 95% significance level ($p = 0.05$).

The average TDN concentrations measured at the second measurement time increased for all three varieties during storage. The rate of increase in concentration in neither the Italian Riesling nor the Kéknyelű wines was such that the resulting TDN concentrations were equal to the TDN concentrations measured in the Rhine Riesling wines. I measured the highest TDN concentrations in the Rhine Riesling wines.

3.3. The effect of vintage on the concentration of TDN in wines

There were no significant differences in TDN concentrations in the studied vintages at the time of the first series of measurements, except the year 2019, when I measured one of the highest TDN concentrations: 63.5 µg/l. In previous years, TDN was measured at low concentrations. The reason for the high TDN in 2019 compared to other years is that the summer was warmer than usual this year compared to the previous (2018) and subsequent (2020) years, with higher global radiation. Excessive exposure of grapes to sunlight leads to high TDN concentrations. From 2016 onwards, by the time of the second series of measurements, the concentration of TDN in wine had increased significantly during storage.

My studies indicate that the impact of vintage on the TDN concentration of wines seems to be much stronger than the age of the wines. The vintage has an impact on grapes, which responds to extreme weather conditions (too high temperatures, too much sunshine, too little rainfall) by producing TDN precursors. The higher concentration of the precursor molecule in the wine can lead to higher concentrations of TDN later in the wine during ageing, resulting in a kerosene side flavour.

3.4. Sensory analysis

A sensory assessment was only made before the first series of measurements, immediately after the bottles were opened. When comparing the scores from the sensory assessment with the measured TDN concentrations, it can be observed that the concentration of the compound does not always follow the sensory appearance. This can be observed for all three varieties of wine.

3.5. TDN concentrations of Wines and closures

In my PhD thesis I also studied the effect of bottle sealing. The domestic Italian Riesling and Rhine Riesling wines I examined were partly bottled with cork stoppers and partly with screw caps.

I also compared the concentrations of TDN measured at the moment of opening the bottles, grouped by mode of sealing. Wines from different vintages were stored in their own bottles from bottling to the moment of opening. Based on statistical analysis, no significant difference was found between the TDN concentrations measured at the moment of bottle opening.

After bottle opening, I investigated the evolution of the TDN concentration as a function of time, taking into account the bottle sealing methods: at the time of the first bottle opening (1st series of measurements) and after half a year (2nd series of measurements). I studied the differences between the TDN concentrations that increased between the two measurement times.

Using the Kruskal-Wallis test, I examined whether there was a detectable difference in the increase in TDN concentration between bottle sealing methods during the first six months.

Under the storage conditions I have implemented, no statistically significant difference in TDN concentration variation could be detected between the bottle sealing types tested.

3.6. Wines from the same winery

Eight bottles of wine samples were Rhine Riesling wines from the same winery, of different vintages. (Fig. 5). As the samples were from the same winery, differences in technology can be excluded.

The TDN concentrations of the 8 wines from the same winery showed a decreasing trend depending on the vintage. I measured the highest TDN concentration in the 2013 vintage wine (15.5 μg/L) and the lowest (0.6 μg/L) in the 2020 vintage wine. I present the evolution of TDN concentrations by vintage in Fig. 5.

By the time of the second measurement, all but 2 wines (vintages 2018 and 2019) had an increase in TDN concentration, but the increase was not significant at 95% confidence level ($p=0.05$). Only the TDN content of the 2010, 2013 and 2016 vintages crossed the recognition threshold.

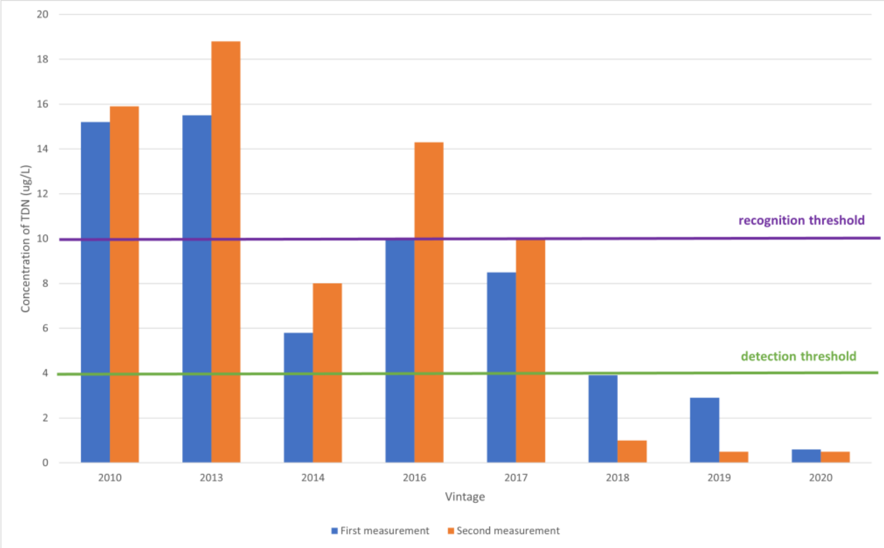

Fig. 5. TDN content of Rhine Riesling wines from the same winery but with different vintages.

In Fig. 5 it can be observed that the TDN concentration in the 2010 vintage wine sample is lower than the TDN measured in the 2013 wine sample. The 2014 vintage does not fit the bill either, with its low concentration of TDN.

3.7. Rhine Riesling wines from foreign countries

I also had the opportunity to measure the TDN concentration in 38 bottles of Rhine Riesling wine from abroad (Germany, Austria, France and Australia). The TDN concentrations obtained for each wine are shown in Fig. 6.

Compared to Hungarian wines, the concentrations found in Hungarian Rhine Rieslings are practically similar, with particular reference to the European wines studied. Due to climatic conditions, Australian wines tend to have higher values.

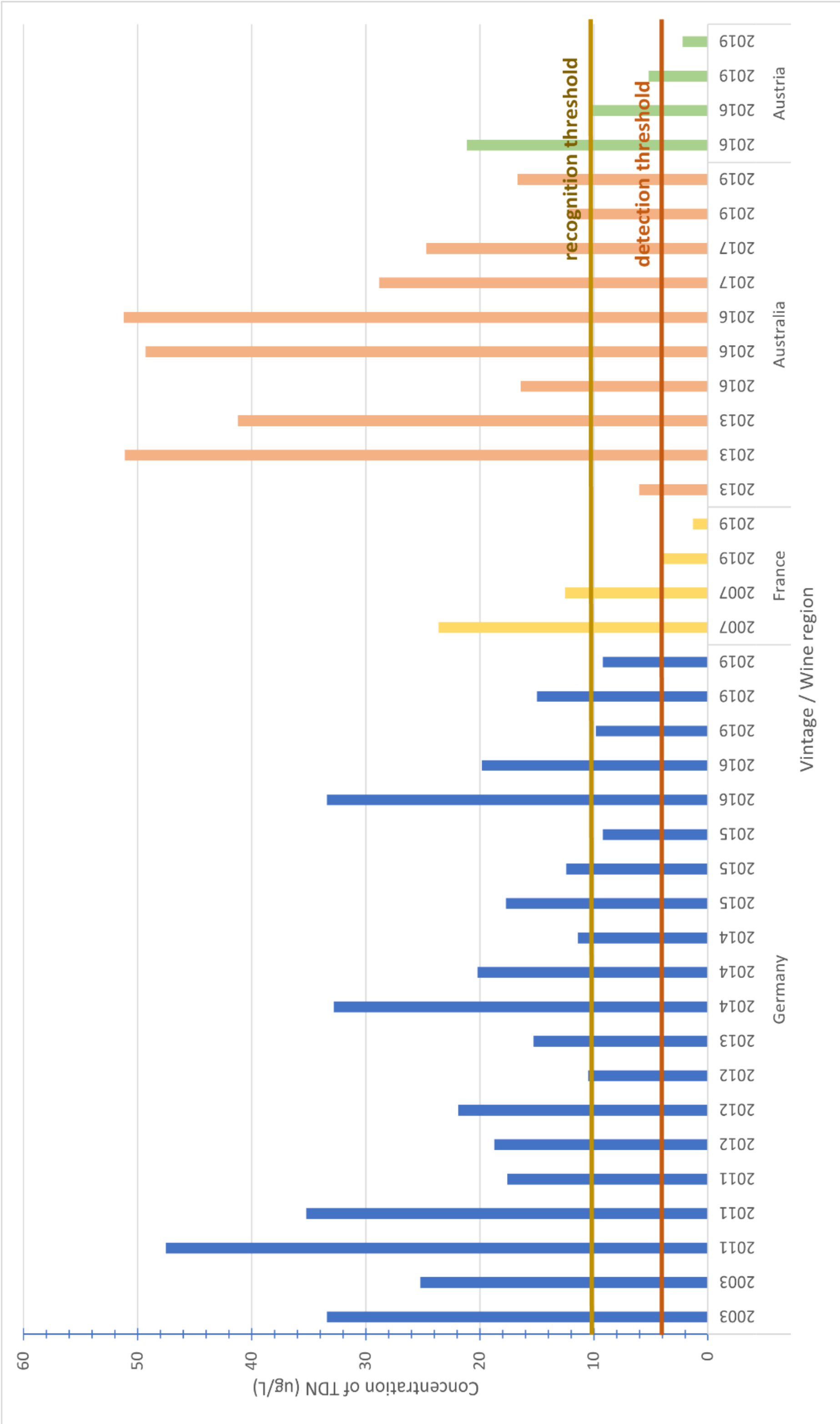

Fig. 6. Concentration of TDN in wines from foreign countries.

4. CONCLUSIONS

There are no data in the technical literature on the TDN content of Hungarian wines (primarily Rhine Riesling and others). In Hungary, I was the first to investigate the evolution of the TDN content causing kerosene taste sensation in domestic Italian Riesling, Rhine Riesling and Kéknyelű wines.

The average TDN concentration of the domestic wines I studied was 1.82 µg/l for Italian Riesling, 12.5 µg/l for Rhine Riesling and 2.0 µg/l for Kéknyelű. For wines made from Kéknyelű grapes, apart from one spiking value (9.1 µg/l), TDN concentrations did not even reach the detection threshold. The comparison of varieties showed that the domestic grape varieties studied showed a different tendency to form higher concentrations of TDN. In the Rhine Riesling wines, significantly higher concentrations of free TDN were formed than in the Italian Riesling or Kéknyelű wines.

I measured the TDN concentration in the wines every 6 months for 24 months. The first measurement was taken immediately after opening the bottle (1st series of measurement), followed by measurements after the 6th (2nd series of measurement), 12th (3rd series of measurement), 18th and 24th months. By month 12, the concentration of TDN in the wines had dropped to the detection limit of the gas chromatography method and remained stable at months 18 and 24. The TDN concentration of the wines tested increased during the first 6 months of storage and then decreased during the next 6 months of storage. The increase may be due to the fact that at the time of the first measurement TDN was still partially bound in the wines, and was released from the bound state by the 6th month of storage. The reason for the decrease is that as the wine ages, TDN is transformed into other compounds, a transformation that is due to the structure of the molecule. The local positive charge of the 7th carbon atom is easily attacked by the oxygen in the air, thus oxidising the TDN compound.

To assess the sensory relevance of TDN, trained wine assessors determined the intensity of kerosene flavour detectable in the wines tested. In the targeted assessment, the odour and taste of the test compound were evaluated on a scale of 1 to 5 points for their recognisability and intensity. Among the components of the wine matrix that determine and influence the sensory properties of wines, I have only examined alcohol, because due to climate change we have to take into account and we are experiencing rising alcohol concentrations, which have increased significantly over the last 20-25 years, by an average of 2 v/v%. It can be concluded that there is no clear significant difference between the sensory assessments and the measured TDN concentrations. Based on my measurement results, it is not clear that the kerosene taste sensation is less perceptible at higher alcohol levels. The influence of additional components in the wine matrix requires further research.

Comparing the foreign Rhine Riesling wines with the domestic wines tested, I found that the TDN concentrations measured in the Rhine Rieslings were similar to those measured in the foreign Rhine Riesling wines. If we want to avoid a kerosene taste in Hungarian Rhine Riesling wines, it is preferable to plant this grape variety in areas with a cooler microclimate and to optimise the period of ageing in bottle.

The effect of the bottle sealing method (cork stopper and screw cap) was investigated with two approaches. The conclusion of both approaches is that the mode of sealing did not influence the development of TDN. Based on my measurements, I recommend the use of screw seals for the three types of seals tested, because of the other advantages of this type of sealing.

The concentration of TDN in Rhine Riesling wines from the same production area, from the same winery, made with the same technology, shows an increasing trend depending on the age and ageing period of the wine, with the oldest wine containing the highest amount of TDN. In the three years between the bottling of the wine and the time of measurement, the TDN concentration had already reached the detection threshold. Therefore, if a wine drinker does not like the taste of kerosene, it is advisable to drink Rhine Riesling bottled as young as possible, but at least less than three years old.

Evaluating the TDN concentrations of all the domestic wines analysed, I measured higher TDN concentrations in the vintages starting from 2017 than in the previous years and the highest concentrations in the 2019 vintage.

The results of the comprehensive TDN determination confirm the susceptibility of domestic Rhine Rieslings to TDN formation. The increase in TDN concentration after 6 months of storage is the result of a slow sugar-bound release in the precursor molecules, leading to a possible initial low free TDN concentration and a high overall TDN formation potential not only in Rhine Riesling but also in Italian Riesling. This release can be caused by higher pH values, lower acid values, different storage conditions (higher temperatures favour release).

The analytical results showed that in Hungary the kerosene taste problem is a topical issue, especially in the case of Rhine Riesling wines. After only a few years of storage, free TDN was present in wines at levels well above the detection threshold (4 μg/l), and also the recognition threshold (10 - 12 μg/l). Individual spikes above 50 μg/l were even in line with wines from significantly warmer countries in international comparisons.

The ageing method used for Rhine Riesling wines is an important factor in preserving the quality of the wine. My studies, but also international practice, mainly study the evolution of the concentration of a given compound during ageing in bottles. In the future, it would be worthwhile to study in more detail the correlation between ageing methods (fine sweeping, different types of wooden barrels, etc.) and TDN development.

I validated the HS-SPME-GC-FID method used for the analytical measurements. Validation data confirm that the method is suitable for accurately quantifying the concentration of free TDN. The lower limit of quantification and the lower limit of detection are low enough to measure TDN concentrations in wines below the detection threshold.

As a consequence of general climate warming, undesirable increases in TDN levels may occur in Hungarian Rhine Riesling and Italian Riesling wines, and possibly also in other varieties. Therefore, it is worth experimenting with viticultural techniques related to the formation and accumulation of precursor carotenoids in grape berries.

At several points, winemaking technology offers the opportunity to prevent high free TDN concentrations in wine:

- The first intervention after harvesting the berries is the pressing of must from the grapes. Gentle pressing can reduce the penetration of TDN precursor molecules into the must, so the application of gentle pressing below 1 bar is recommended.

- An increase in the amount of C_{13}-norisoprenoids in the berry skin as precursors of TDN can be expected with increasing contact time between the must and the berry skin. Therefore, avoiding contact between must and berry skin for as short a time as possible, i.e. avoiding mash soaking, may be important to prevent TDN formation.
- Yeast fungi play a key role in the formation of many aroma compounds, including the enzymatic release of glycosidically bound precursor compounds. Therefore, the selection of a suitable yeast with low β-glucosidase enzyme activity is recommended. In addition, yeast metabolism is influenced by external parameters such as fermentation temperature, pH and the amount of assimilable nitrogen. Setting up experiments to test the effect of these parameters could be recommended.
- The concentration of aroma components in wines can be controlled by further processing before bottling and storage. Different membrane filtration techniques can reduce the amount of glycosidically bound compounds.
- During the storage of wine, acid-catalysed reactions take place, leading, among other things, to the release of bound TDN. These reactions accelerate as the temperature rises, so the increase in the concentration of TDN in wine can be slowed by cooler storage temperatures. When ageing and storing wines in bottles for longer periods, it is recommended to keep them at a temperature at even 5°C.

As a result of the climate change experienced also in Hungary, especially due to the sun's rays, increased carotenoid concentrations in grape berries may result in higher levels of TDN in wines from other grape varieties. In the future, it may be of interest to determine the TDN concentration in wines made from other grape varieties that are primarily considered to be Hungaricums, especially those for which the effect of ageing time on quality may be important (Rózsakő, Zeusz, Furmin, etc.).

5. NEW SCIENTIFIC RESULTS

1. I was the first to determine the TDN concentration of Rhine Riesling, Italian Riesling and Kéknyelű wines in Hungary.

2. I was the first to establish that the measured free TDN concentrations in Hungarian Rhine Riesling wines ranged from 0.6 to 63.5 μg/l in the studied batch, and from 0.04 to 7.0 μg/l in Italian Riesling wines. I detected TDN above the recognition threshold in several Italian Riesling wines. I concluded that the Rhine Riesling has a significantly greater tendency to form TDN at 95% significance level ($p = 0.05$) compared to the Italian Riesling and the Kéknyelű wines. Based on my measurements, comparing the tested foreign Rhine Riesling wines with the tested Hungarian wines, it can be concluded that there is a significant difference between the TDN concentration of the domestic Italian Riesling and Kéknyelű wines and the TDN concentration of the foreign wines (1.3 - 51.2 μg/l) at $p=0.05$ significance level, which means that the average concentration of TDN is lower in the tested domestic wines.

   There is no significant difference between the TDN content of domestic Rhine Riesling wines and foreign Rhine Riesling wines.

3. I was the first to measure the TDN concentration of the autochthonous Hungarian variety used for comparison, Kéknyelű, which was found to be 0.1 - 9.1 μg/l. Some Kéknyelű wines had TDN concentrations above the detection threshold.

4. I concluded that for wines from the same production area, from the same winery, made with the same technology, TDN concentration shows a linear increase as a function of ageing time.

5. I concluded that there is no significant difference between the two types of bottle sealing: cork and screw caps.

6. In terms of sensory assessments, I found that no significant difference was found in the test of the relationship between kerosene taste sensation and alcohol content.

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