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CHARACTERISTIC OF VOLATILE COMPONENTS PROFILE IN POLISH WINES BY GC-MS

S u m m a r y

Background. Wine is a complex mixture of various compounds with diverse structures and properties. Multiple factors influence the chemical composition of wine. Viticulture is at a disadvantage in Poland, compared to more traditional wine regions. Grapes grown in Poland have lower sugar content, which leads to lower alcohol content and higher acidity of produced wine, which could also be seen as an advantage. Aromatic compounds, which are the subject of this study, influence, along with other factors, the taste and aroma of wine.

Results and conclusions. This paper presents results of gas chromatography-mass spectrometry (GC-MS) analysis and characteristic of aroma profiles of Polish wines. We identified 94 volatile compounds in 13 red wines and 53 volatile compounds in 18 white wines, including the following groups of compounds: alcohols, acids, esters, carbonyl compounds, ethers, terpenoids, norisoprenoids, phenols, sulfur compounds and hydrocarbons. The wines were produced from various grape varieties. A comparison of obtained results, both between each other and with results obtained in different studies, showed differences in wine composition, based on various factors. Odor Activity Values (OAVs) were calculated to define the dominant aroma of the analyzed wines, the higher the OAV of a given compound is, the greater impact on wine aroma it has.

Keywords: GC-MS, OAVs, Polish wines, volatile compounds

Introduction

Wine is a complex mixture of various compounds with diverse structures and properties, such as amino acids, carbohydrates, phenolic compounds, proteins, volatile and inorganic compounds, at different concentration levels. Multiple factors, such as

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vintage, climate, geographical location, grape variety, yeast strains and wine production processes, including fermentation, largely influence the chemical composition of wine [1]. According to Council Regulation (EC) No 491/2009 of 25 May 2009, amending Regulation (EC) No 1234/2007 establishing a common organization of agricultural markets and on specific provisions for certain agricultural products, Poland is considered to be part of the wine-growing zone A, which is the coldest wine-growing zone in Europe [6, 14]. Conditions for viticulture are worse in Poland than in traditional, typical wine regions. Polish climate and soil cause lower sugar content in grapes, often between 17 to 23 %, which leads to lower alcohol content, higher acidity, better accumulation of certain aroma compounds, including higher polyphenols concentration in produced wine. What can also be seen as an advantage of Polish wine is less sweet and higher acidity, which makes wine more crisp and fresh in taste, especially when it comes to white wines [14]. Polish vineyards are usually family businesses that develop their own characteristic style, being often the result of many years of searching for a suitable place to start a vineyard and depending on grape varieties used and type of wine produced. To counteract unfavorable soil conditions, special preparations, such as effective microorganisms (EM), can be used. They increase the quality of soil, strengthen vines and can be used, among others, in de Sas winery in Dolina Baryczy. Many places in Poland have their own "terroir", unique microclimate and soil conditions, which can positively influence the cultivation of vines. An example of that is Patria vinery, in Upper Silesia, which is located near a river. That location provides a characteristic microclimate and increases the quality of vines. Various grape varieties are grown in Poland, and since grapes and chemical compounds they contain are sensitive to environmental conditions, the quality and characteristics of Polish wines will be different than of wines produced from the same grape varieties, but in a different climate. Wine aroma is one of the deciding factors when choosing wine and it depends on grape-derived compounds, vintage, fermentation and a storage method. The flavor of wine is a result of the presence of specific compounds characteristic to a grape variety used and compounds derived from the fermentation and maturation of wine [32]. Over 1,000 aroma compounds were identified in wines, such as acids, alcohols and terpene alcohols, aldehydes, esters, ethers, hydrocarbons, ketones, lactones, nitrogen and sulfur compounds, and they can occur at various levels of concentration [4]. All those aromatic compounds can influence the taste and aroma of wine. It was possible, in some researches, to pinpoint several key compounds that were largely responsible for a wine taste. However, in most cases, various compounds interact with each other and their specific ratio and combination create the wine taste and aroma [4, 9]. Understanding the role of key aroma compounds helps to control the quality of produced wine and helps to choose correct and suitable wine growing and production processes [4]. The aim of this study was to determine volatile organic compounds present in various wines from Polish vineyards by GC-MS analytical technique. Moreover, the evaluation of the contribution of aroma compounds to Polish wines through the calculation of OAVs was made. Based on this study, it can be possible to illustrate the aroma fingerprints differences of those compounds involved in the final aroma of wine from Poland.

Material and methods

Wine samples

In this study 31 wine samples were analyzed, 18 white wines and 13 red wines. All the wines were produced in Poland from the following grape varieties. White wines were produced from Seyal Blanc, Riesling, Sibera, Hibernal, Gewürztraminer, Chardonnay and Solaris, while red wines were produced from Pinot Nor, Regent, Rondo, Zweigelt and Cabernet Cortis. Most of the samples, 23, were produced from one grape variety, and eight samples were produced from at least two different grape varieties. The wines were produced in the following provinces: Świętokrzyskie Province (five wines), Małopolskie Province (eight), Dolnośląskie Province (ten), Lubuskie Province (two), Śląskie Province (three), Podkarpackie Province (one) and Zachodniopomorskie Province (two). The dominating aroma of the analyzed wines was fruity, with only three samples of white wine not having fruity aroma according to producers. The wine samples were spiked with 2.5 $mg \cdot l^{-1}$ of 2-octanol (98 % purity) as Internal Standard (IS) [4].

SPME sample conditions

The wine samples (0.3 cm^3, undiluted) were pipetted into 1.5 cm^3 round-bottomed, glass vials, each containing 90 mg (± 1 mg) NaCl. The vials were immediately placed in the instrument for an analysis. A 2 cm 50/30 μm divinylbenzene/carboxen/ polydimethylsiloxane (DVB/CAR/PDMS) (Supelco, USA), 23-gauge SPME fiber was used for sampling. The samples were warmed at 35 °C and agitated for 5 minutes before exposing the fiber for 30 minutes at 35 °C with agitation. This was immediately followed by the desorption of the analytes at 250 °C into the gas chromatograph injector [5, 12]. The solid-phase fiber remained in the injector for about 5 min. All the samples were analyzed in triplicate.

GC-MS analysis

This profiling method was developed using a ISQ QD mass spectrometer coupled to a Trace 1310 GC equipped with a TriPLUS RSH autosampler (Thermo Fisher Scientific, USA). Due to the applied SPME technique, splitless injection mode and liner 0.8 mm i.d. were used. Compounds were separated on a polar column Zebron ZB-Wax, 30 m length x 0.25 mm ID, 0.25 μm film thickness (Phenomenex, USA). Helium was used as a carrier gas with a column flow rate of 1.0 ml·min^{-1}. Temperature program: 40 °C hold for 10 minutes, ramp 2 °C·min^{-1} to 200 °C, hold for 1 minute, ramp 2 °C·min^{-1} to 250 °C, hold for 10 minutes. The selective mass detector was operated at 70 eV in the EI mode over the m/z range 30 ÷ 350, scanned at 0.2 s intervals and temperature transfer line 250 ^{o}C.

Qualitative analysis and quantification

The constituents were identified by comparing their Kovats retention indices with those from the literature, reference compounds, computer matching against the NIST 11, data obtained from NIST Chemistry WebBook databases. The quantification was carried out following the internal standard quantification method. The 2-octanol was chosen as internal standard, due to the fact that it did not exist in the analyzed wines, and is used to determine the profile of volatile organic compounds in alcoholic beverages [2, 11, 18]. The concentration of the identified component was obtained by interpolation of the relative areas of these compounds versus the internal standard area in calibration graphs obtained for reference compounds, similarly to other studies [2, 10, 11, 16, 18]. The concentration of the components for which there was no available standards was obtained from calibration graphs as one of compounds with a similar chemical structure [21].

Results and discussion

Aroma compounds in wines

In this study, 94 volatile compounds in red wines and 53 volatile compounds in white wines, including the following groups of compounds: alcohols, acids, esters, carbonyl compounds, ethers, terpenoids, norisoprenoids, phenols, sulfur compounds and hydrocarbons (Table 1) were determined. Not all the analyzed compounds were determined in every wine sample. In the figures, chromatograms from the analysis of the Polish white and red wine samples were presented (Fig. 1a and 1b).

The most important aroma compounds that come from grapes used in wine production are monoterpenes, which mostly occur as alcohols, ethers and hydrocarbons, norisoprenoids, benzenoid compounds that originate from shikimic acid and sulfured compounds. Monoterpenes provide basic floral aroma, and C_6 alcohols rose-like scent, higher alcohols and ethyl esters of $C_4 \div C_{10}$ fatty acids contribute to the fruity scents, while the occurrence of norisoprenoids is connected with some specific ageing aroma and abundance of fatty acids that can contribute to a “goaty” flavor of wine [25]. Somkuwar et al. [23] evaluated aroma composition by analyzing 64 compounds in various red wines (Cinsaut, Grenache, Cabernet Franc, Petit Verdot, Cabernet Sauvignon, Nielluccio, Tempranillo, Syrah, Merlot and Caladoc) made from grapes grown

Table 1. Concentrations, LOD (limit of detection) and RI (retention index) values of analyzed compounds in white and red wines [$\mu g \cdot l^{-1}$]

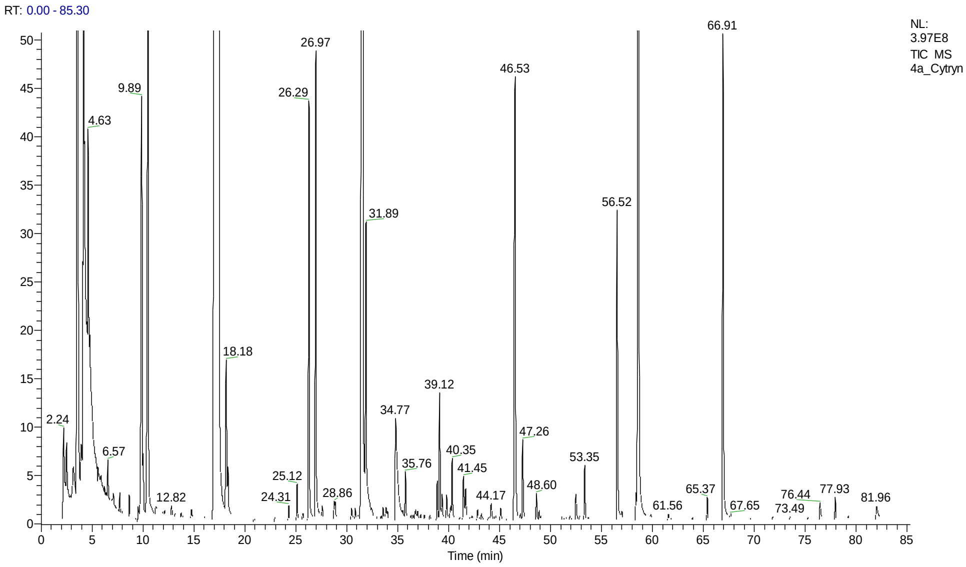
Tabela 1. Stężenia, wartości granic oznaczalności i indeksów retencji dla analizowanych związków w białych i czerwonych winach [$\mu g \cdot l^{-1}$]

Compound / Związek	RI	LOD	White wines (n = 18) / Białe wina (n = 18)			Red wines (n = 13) / Czerwone wina (n = 13)		
			Min / Min	Max / Maks	Mean / Średnia	Min / Min	Max / Maks	Mean / Średnia
Acids / Kwasy								
acetic / octowy	1442.00	5.41	54.09	321.78	154.10	<LOD	487.55	302.05
pentanoic / n-pentanowy	1713.00	0.27	<LOD	784.83	87.37	26.22	76.59	43.44
4-hydroxy butanoic / 4-hydroksybutanowy	1633.00	0.93	<LOD	<LOD	-	<LOD	42.66	28.81
isobutanoic / izobutanowy	1581.00	0.32	<LOD	50.69	14.54	<LOD	51.27	35.56
butanoic / butanowy	1651.00	0.26	4.90	55.51	20.87	<LOD	19.34	19.34
2-methylbutanoic / 2-metylobutanowy	1686.00	0.27	<LOD	<LOD	-	<LOD	148.90	66.86
3-methylbutanoic / 3-metylobutanowy	1691.00	0.31	<LOD	<LOD	-	<LOD	40.63	36.40
hexanoic / heksanowy	1866.00	0.22	<LOD	458.90	289.85	121.97	319.04	217.76
2-ethylhexanoic / 2-etyloheksanowy	1962.00	0.25	5.43	11.88	7.47	<LOD	11.34	7.56
octanoic / oktanowy	2050.00	0.20	424.72	917.88	687.15	150.08	646.85	342.12
nonanoic / nonanowy	2171.00	0.17	2.38	8.13	5.98	<LOD	5.08	5.08
decanoic / dekanowy	2279.00	0.11	<LOD	206.17	75.52	6.19	83.53	29.71
2,4-hexadienoic acid / 2,4-heksadienowy	2150.00	0.12	<LOD	1157.70	590.63	<LOD	<LOD	-
9-decenoic acid / 9-decenowy	2335.00	0.13	<LOD	12.65	5.34	<LOD	<LOD	-
Esters / Estry								
ethyl acetate / octan etylu	880.00	0.45	857.51	1532.02	1107.50	1331.53	2371.03	1776.79
isobutyl acetate / octan izobutylu	1015.00	0.21	<LOD	<LOD	-	<LOD	23.35	23.35
ethyl butanoate / butanian etylu	1021.00	0.19	37.52	141.51	66.97	21.11	91.62	43.10
ethyl 2-methylbutanoate / 2-metylobutanian etylu	1042.00	0.13	<LOD	<LOD	-	<LOD	185.93	106.68
ethyl 3-methylbutanoate / 3-metylobutanian etylu	1064.00	0.18	<LOD	<LOD	-	<LOD	86.41	35.69
3-methyl-1-butyl acetate / octan 3-metylo-1-butylu	1126.00	0.17	392.83	1636.15	1025.23	<LOD	1249.66	628.81
methyl isohexanoate / izoheksanian metylu	1136.00	0.25	<LOD	<LOD	-	<LOD	4.07	4.07
ethyl 2-butenoate / 2-butenian etylu	1157.00	0.12	<LOD	19.93	5.81	<LOD	7.34	6.72
methyl hexanoate / heksanian metylu	1177.00	0.11	2.13	32.53	13.50	<LOD	10.56	9.40
ethyl hexanoate / heksanian etylu	1223.00	0.15	156.88	463.66	287.12	<LOD	262.20	150.61
hexyl acetate / octan heksylu	1278.00	0.23	<LOD	152.33	49.55	<LOD	9.63	6.80
ethyl 2-hexanoate / 2-heksanian etylu	1340.00	0.19	<LOD	17.02	9.23	<LOD	18.34	12.15
ethyl lactate / mleczan etylu	1347.00	0.40	14.51	520.96	102.45	421.20	795.61	550.80
methyl octanoate / oktanian metylu	1388.00	0.16	12.35	95.05	43.48	<LOD	15.22	11.14
ethyl octanoate / oktanian etylu	1422.00	0.13	166.12	763.66	370.98	77.38	327.06	213.95
ethyl 3-hydroxybutanoate / 3-hydroksybutanian etylu	1515.00	0.32	<LOD	<LOD	-	<LOD	21.22	12.96
amyl lactate / mleczan amylu, pentylu	1610.00	0.21	<LOD	<LOD	-	<LOD	13.06	8.01
isopentyl methoxyacetate / metoksyoctan izopentylu	1570.00	0.38	<LOD	<LOD	-	<LOD	108.49	73.42
isoamyl lactate / mleczan izopentylu	1577.00	0.62	<LOD	<LOD	-	<LOD	86.94	39.66
ethyl methyl succinate / bursztynian etylu i metylu	1631.00	0.76	<LOD	<LOD	-	<LOD	30.33	25.19
ethyl decanoate / dekanian etylu	1643.00	0.43	<LOD	<LOD	-	<LOD	14.35	8.82
diethyl succinate / bursztynian dietylu	1674.00	0.43	<LOD	561.99	221.76	121.47	1191.13	499.74
methyl salicylate / salicylan metylu	1735.00	0.17	<LOD	<LOD	-	<LOD	22.30	13.68
ethyl phenylacetate / fenylooctan etylu	1783.00	0.15	<LOD	<LOD	-	<LOD	7.10	7.10
ethyl butyl succinate / bursztynian etylu i butylu	1814.00	0.52	<LOD	<LOD	-	<LOD	14.44	13.33
2-phenethyl acetate / octan 2-fenetylu	1826.00	0.17	13.38	172.54	62.09	<LOD	117.04	39.12
ethyl-3-methylbutyl butanoate / butanian etylo-3-metylobutylu	1861.00	0.14	<LOD	<LOD	-	<LOD	86.35	33.21
diethyl phthalate / ftalan dietylu	2352.00	0.14	<LOD	<LOD	-	<LOD	14.88	7.69
ethyl hydrogen succinate / wodorobursztynian etylu	2367.00	0.11	<LOD	54.29	25.39	<LOD	117.96	54.34

ethyl sorbate / sorbinian etylu	1501.00	0.22	<LOD	938.42	351.45	<LOD	<LOD	-
ethyl leucate / 2-hydroksy-4-metylopentanian etylu	1547.00	0.21	5.93	241.37	76.19	<LOD	<LOD	-
diethyl hydroxybutanoate / hydroksybutanian dietylu	2039.00	0.41	3.18	67.73	15.11	<LOD	<LOD	-
Alcohols / Alkohole								
1-propanol / 1-propanol	1038.00	0.49	<LOD	58.70	26.50	<LOD	172.84	70.66
2-methyl-1-propanol / 2-metylo-1-propanol	1114.00	0.38	178.14	1061.87	578.69	642.46	1410.75	1021.08
1-butanol / 1-butanol	1145.00	0.42	4.12	29.89	13.46	15.96	122.69	34.92
cyclopentanol / cyklopentanol	1300.00	0.20	<LOD	<LOD	-	<LOD	10.08	6.98
3-methyl-1-butanol (isoamylol) / 3-metylo-1-butanol	1211.00	0.28	3169.75	6589.83	4687.77	4205.80	7115.36	5792.30
3-methyl-3-buten-1-ol / 3-metylo-3-buten-1-ol	1245.00	0.34	<LOD	<LOD	-	<LOD	4.03	4.03
1-pentanol / 1-pentanol	1269.00	0.11	<LOD	<LOD	-	<LOD	9.68	3.93
4-methyl-1-pentanol / 4-metylo-1-pentanol	1314.00	0.19	2.00	16.10	7.61	<LOD	56.27	19.53
2-heptanol / 2-heptanol	1321.00	0.41	<LOD	<LOD	-	<LOD	19.80	10.24
3-methyl-1-pentanol / 3-metylo-1-pentanol	1334.00	0.22	7.12	38.14	18.89	9.15	70.73	39.13
1-hexanol / 1-heksanol	1359.00	0.35	358.75	951.33	664.72	533.58	1581.49	1071.22
3-hexen-1-ol / 3-heksen-1-ol	1372.00	0.49	4.11	27.34	13.52	7.26	38.23	19.87
3-ethoxy-1-propanol / 3-etoksy-1-propanol	1382.00	0.22	<LOD	20.20	8.17	<LOD	33.91	13.69
4-hexen-1-ol / 4-heksen-1-ol	1401.00	0.41	<LOD	<LOD	-	<LOD	35.14	18.29
3-octanol / 3-oktanol	1409.00	0.27	<LOD	<LOD	-	<LOD	5.93	4.92
1-octen-3-ol / 1-okten-3-ol	1452.00	0.35	<LOD	<LOD	-	<LOD	13.33	8.46
1-heptanol / 1-heptanol	1461.00	0.43	<LOD	48.80	19.58	31.84	93.46	50.68
2-propyl-1-pentanol / 2-propylo-1-pentanol	1484.00	0.47	<LOD	<LOD	-	<LOD	91.77	91.77
2-ethyl-1-hexanol / 2-etylo-1-heksanol	1491.00	0.52	13.05	106.62	35.56	<LOD	227.20	69.30
2-nonanol / 2-nonanol	1521.00	0.51	<LOD	<LOD	-	<LOD	13.14	8.67
2,3-butanediol / 2,3-butanodiol	1543.00	1.35	23.93	241.37	93.13	<LOD	306.49	184.05
1-octanol / 1-oktanol	1556.00	0.66	7.05	44.50	23.80	29.41	55.43	41.80
1,2-propanediol (propylene glycol) / 1,2-propanodiol	1599.00	1.12	<LOD	<LOD	-	<LOD	15.61	15.61
1-nonanol / 1-nonanol	1660.00	0.74	<LOD	<LOD	-	<LOD	28.14	16.88
2-furanmethanol / 2-furanometanol	1669.00	0.10	<LOD	54.21	14.17	<LOD	46.36	28.94
benzyl alcohol / alkohol benzylowy	1877.00	0.16	<LOD	<LOD	-	<LOD	217.20	49.54
2-phenylethanol / 2-fenyloetanol	1912.00	0.24	350.35	1370.04	753.60	647.48	2014.32	1176.03
1,2,3-propanetriol (glycerine) / 1,2,3-propanotriol	2316.00	1.91	<LOD	<LOD	-	<LOD	640.45	346.12
Carbonyl compounds / Związki karbonylowe								
acetaldehyde / aldehyde octowy	740.00	0.12	<LOD	<LOD	-	<LOD	168.43	80.34
2-butanone / 2-butanon	923.00	0.21	<LOD	<LOD	-	<LOD	26.44	26.44
2-octanone / 2-oktanon	1297.00	0.13	<LOD	<LOD	-	<LOD	10.12	10.12
3-hydroxy-2-butanone / 3-hydroksy-2-butanon	1286.00	0.37	<LOD	<LOD	-	<LOD	8.91	7.52
nonanal / nonanal, aldehyd pelargonowy	1394.00	0.15	<LOD	<LOD	-	<LOD	7.10	7.10
furfural / furfural	1468.00	0.16	<LOD	65.89	16.32	<LOD	114.29	48.31
benzaldehyde / benzaldehyd	1508.00	0.18	<LOD	<LOD	-	<LOD	515.62	193.71
γ-butyrolactone / γ-butyrolakton	1626.00	0.10	<LOD	<LOD	-	<LOD	41.87	24.59
2,4-dimethylbenzaldehyde / 2,4-dimetylobenzaldehyd	1710.00	0.12	<LOD	<LOD	-	18.53	36.78	26.57
2-tert-butyl-5-propyl-1,3-dioxolan-4-one / 2-tert-butylo-5-propylo-1,3-dioksolan-4-on	1820.00	0.27	<LOD	<LOD	-	<LOD	7.10	7.10
trans-3-methyl-4-octanolide / trans-3-metylo-4-oktanolid	1861.00	0.26	<LOD	<LOD	-	<LOD	5.78	5.78
5-butyl-4-methyloxolan-2-one (whiskey lactone) / 5-butyl-4-metyloksolan-2-on	1910.00	0.37	<LOD	<LOD	-	<LOD	12.81	9.38
3,5-dimethylbenzaldehyde / 3,5-dimetylobenzaldehyd	1837.00	0.19	16.17	42.05	28.68	<LOD	<LOD	-
Ethers / Etery								
1-(1-ethoxyethoxy)pentane / 1-(1-etoksyetoksy)pentan	1109.00	0.41	<LOD	<LOD	-	<LOD	18.10	17.17
1-(1-ethoxyethoxy)hexane / 1-(1-etoksyetoksy)heksan	1258.00	0.20	<LOD	<LOD	-	<LOD	<LOD	-
Phenols / Fenole								
4-ethyl-2-methoxyphenol / 4-etylo-2-	2033.00	0.52	<LOD	<LOD	-	<LOD	22.20	14.47

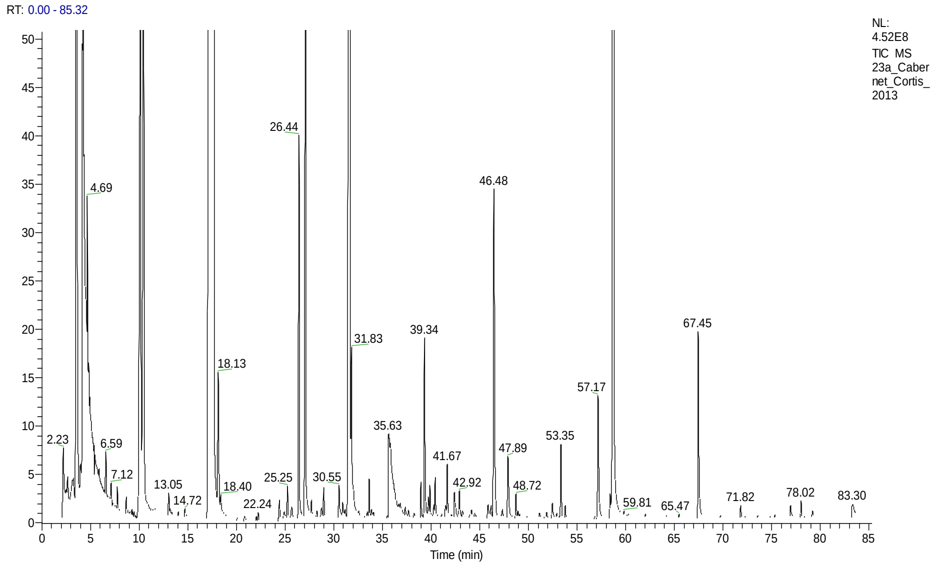
metoksyfenol								
4-ethylphenol / 4-etylofenol	2164.00	0.41	<LOD	<LOD	-	<LOD	259.82	78.73
2,4-ditertbutylphenol / 2,4-di-tert-butylofenol	2330.00	0.79	19.79	34.59	26.89	14.15	30.34	22.94
Sulfur compounds / Związki siarki								
dimethyl sulfide / siarczek dimetylu	716.00	0.31	<LOD	<LOD	-	<LOD	28.13	28.14
3-methylthio-1-propanol / 3-metylotio-1-propanol	1717.00	0.78	<LOD	26.90	11.98	<LOD	110.83	52.34
Hydrocarbons / Węglowodory								
undecane / undekan	1100.00	0.73	<LOD	<LOD	-	<LOD	64.23	36.16
Terpenoids / Terpenoidy								
cis-rose oxide / tlenek cis-róży, cis-rose	1339.00	0.22	<LOD	17.07	8.73	<LOD	<LOD	-
nerol oxide / tlenek nerolu	1465.00	0.18	<LOD	199.26	45.87	<LOD	<LOD	-
linalool / linalol	1537.00	0.76	11.34	119.20	51.91	<LOD	213.54	113.88
hotrienol / hotrienol	1607.00	0.27	10.72	363.42	85.05	<LOD	<LOD	-
α-terpineol / α-terpineol	1708.00	0.31	9.86	91.78	35.65	<LOD	<LOD	-
terpineol / α-terpineol	1680.00	0.69	<LOD	<LOD	-	<LOD	22.04	17.16
3,7-dimethyl-6-octen-1-ol (citronellol) / 3,7-dimetylo-6-okten-1-ol	1769.00	0.42	<LOD	22.84	7.42	<LOD	7.04	5.58
Norisoprenoids / Norisoprenoidy								
β-damascenone / β-damascenone	1801.00	0.74	<LOD	<LOD	-	<LOD	54.43	54.43

Explanatory notes / Objaśnienia:
RI – retention index / indeks retencji; LOD – limit of detection / limit wykrywalności



1 a

Fig. 1a. Chromatogram of white wine from Śląskie Province after GC-MS analysis.
Rys. 1a. Chromatogram wina białego z województwa śląskiego na podstawie analizy GC-MS.



1 b

Fig. 1b. Chromatogram of red wine from Małopolskie Province after GC-MS analysis.
Rys. 1b. Chromatogram wina czerwonego z województwa małopolskiego na podstawie analizy GC-MS.

under tropical conditions of India. Alcohols were found to be the most dominant group of volatile compounds identified in tested wines, followed by esters and acids, with lower concentrations of aldehydes, phenols and terpenes [23]. In our study, alcohols were also found to be the dominant group of volatile compounds, followed by esters and acids. Carbonyl compounds, phenols, norisoprenoids, sulfur compounds, hydrocarbons, terpenoids and ethers were found at lower concentrations. Longo et al. (2020) conducted a preliminary study on Pinot noir wines from five Australian winegrowing regions (Adelaide Hills, Yarra Valley, Mornington Peninsula, Northern and Southern Tasmania). In the study, 27 compounds were determined – alcohols, esters, acids and norisoprenoids [17]. Qian et al. [22] characterized 114 volatile compounds of Cabernet Sauvignon wines from two different clones during oak barrel aging. In our study, Polish wines produced from other Cabernet grape varieties were analyzed – Cabernet Dorsa and Cabernet Cortis and we determined 104 volatile compounds in them. Zhao et al. [31] characterized volatile aroma compounds in litchi (Heiye) wine and distilled spirit. They observed 128 different aroma compounds, which belonged to six chemical groups: esters, alcohols, acids, terpenes, aldehydes and ketones, and other compounds, and 59 of them were determined in litchi wine [31]. Issa-Issa et al. determined 54 volatile compounds (alcohols, esters, acids, aldehydes, lactones, phenols, hydrocarbons and ketones) in Fondillón, which is a wine made from overripe grapes of the Monastrell variety [13]. Fandiño et al. [7] analyzed the chemical composition and sensory properties of Albariño wine and impact of fertigation on wine content. They determined 31 volatile compounds, and their concentration was different depending on fertigation used [7]. Lan et al. (2021) characterized key odor-active compounds in sweet Petit Manseng (*Vitis vinifera* L.) wine by determining 42 aroma compounds [15]. Nicolotti et al. [20] analyzed 36 key aroma compounds in Australian Cabernet Sauvignon red wine. The highest concentrations were determined for acetic acid, 3-methylbutanol, 2-methylbutanol, methylpropanol and 2-phenylethanol, which are important odorants and can be produced during microbial fermentation [20]. Benkwitz et al. [3] examined 17 compounds, determined with the highest OAV values, in Sauvignon Blanc wines. 3-Mercaptohexanol and 3-mercaptohexyl acetate were found to be the most important odorants, with β-damascenone and varietal thiols, esters, terpenes and higher alcohols being key aroma compounds [3]. Mayr et al. [19] analyzed 48 aroma compounds in Shiraz wine from two regions – Barossa Valley and Margaret River. The highest concentrations were determined for acetic acid, ethyl lactate and ethyl acetate, and the highest OAV values for ethyl octanoate, β-damascenone, ethyl hexanoate and ethyl 3-methylbutanoate [19].

Acids

We determined 13 acids in analyzed wines (Table 1). It is worth noting that fatty acids are considered to be acids with the biggest impact on wine aroma. Their excess can contribute to an unpleasant flavor, while the right concentration to a pleasant, fresh flavor [24]. The highest concentrations were determined for octanoic acid, 2,4-hexadienoic acid and hexanoic acid in white wines, and for octanoic acid, acetic acid and hexanoic acid in red wines. White wine samples with the highest total mean acid concentration were three samples having a tropical and citrus fruit aroma, while for red wines these were three samples having a red and forest fruit aroma. It is worth emphasizing that the highest total mean concentrations of the analyzed acids were found in the samples having fruit aromas, for both white and red wines. Somkuwar et al. [23] analyzed 12 acids – acetic acid, dodecanoic acid, hexanoic acid, n-decanoic acid, nonanoic acid, octanoic acid, oxalic acid, pentadecanoic acid, propanoic acid, 2-methylpropanoic acid, tetradecanoic acid and undecanoic acid. The concentrations ranged from 10 $\mu g \cdot l^{-1}$ (propanoic acid in Cabernet Franc and Caladoc wines, oxalic acid in Cabernet Franc, Merlot and Caladoc wines) to 14.5 $mg \cdot l^{-1}$ (acetic acid in Grenache wine). The highest concentrations were determined for acetic acid, oxalic acid, octanoic acid and hexanoic acid, which is comparable to the results obtained in this study for red wine with octanoic acid, acetic acid and hexanoic acid being determined with the highest concentrations out of all detected acids. The highest values obtained for those acids in this study were lower than the highest values obtained by Somkuwar et al. [23]. Zhao et al. [31] determined 11 acids in litchi wine. The highest concentrations were determined for decanoic acid (993.17 $\mu g \cdot l^{-1}$), octanoic acid (964.80 $\mu g \cdot l^{-1}$) and 3,7-dimethyl-6-octadienoic acid (373.26 $\mu g \cdot l^{-1}$). The lowest concentrations were determined for methylenecyclopropane-2-carboxylic acid (13.10 $\mu g \cdot l^{-1}$) and hexanoic acid (52.38 $\mu g \cdot l^{-1}$). In our study, the highest concentration of decanoic acid was determined in white wine sample, and it was lower than the value obtained for litchi wine. The highest concentration of octanoic acid was determined in another white wine sample, and it is comparable to the value obtained for litchi wine. In our study, hexanoic acid concentrations were higher, in both white and red wine, than the values obtained for litchi wine [31].

Esters

We analyzed 32 esters, which are the main volatile compounds in wines [32]. They contribute to the fruity aroma of young wines and their concentration can change during wine ageing, which is caused by esterification and hydrolysis [24]. Ethyl and acetate esters are associated with fruity and floral aromas [27]. In red wines, the highest concentrations were determined for ethyl acetate, isoamyl acetate and ethyl lactate, and in white ones, they were determined for ethyl acetate and isoamyl acetate. It is worth emphasizing that ethyl and acetate esters are typically associated with fruity and floral aromas [27]. High concentration of isoamyl acetate is connected with a pear aroma, and we determined its high concentration in wine with a pear aroma. On the other hand, high concentrations of ethyl cinnamate and ethyl hexanoate can contribute to unfavorable odors of wax and honey [30]. The highest concentration of ethyl hexanoate was determined for the white wine sample with banana, pear and gooseberry aromas, however, ethyl cinnamate was not determined in that sample. Sonni et al. reported that 2-phenylethyl acetate is a compound that can enhance floral and sweet aromas in young white wines, especially when it occurs alongside another compound having a sweet aroma, such as isoamyl acetate [24]. We determined both isoamyl acetate and 2-phenylethyl acetate in the Polish white wine samples, which confirms their impact on the aroma of wines. Another compound, whose presence is connected with floral and fruity aromas, is hexyl acetate [27], which was determined in our samples, but at low concentrations. High concentrations of 4-methyl-3-hexanol, ethyl-3-hydroxybutanoate, 3-ethoxy-1-propanol, isoamyl acetate, ethyl hydrogen succinate and diethyl malate can contribute to fruity, apple skin like, banana, grape-like, sweet and sugar aromas. We determined 3-ethoxy-1-propanol, isoamyl acetate, ethyl-3-hydroxybutanoate and ethyl hydrogen succinate in red wines, and 3-ethoxy-1-propanol, isoamyl acetate, diethyl malate and ethyl hydrogen succinate in white wines. All the red wine samples and most of the white wine samples, except for three samples, had fruit aromas. Qian et al. [22] analyzed 35 esters in Chinese Cabernet Sauvignon wines. The highest concentrations were determined for ethyl acetate (64580 $\mu g \cdot l^{-1}$), ethyl lactate (53020 μg·l^{-1}) and diethyl succinate (3020 μg·l^{-1}). Those esters were also determined at the highest concentrations in Polish wines produced from Cabernet Cortis and combination of Cabernet Dorsa, Zweigelt, Rondo and Regent, together with isoamyl acetate, but at significantly lower concentrations. The lowest concentration was determined for ethyl undecanoate (0.14 μg·l^{-1}), which was not analyzed in our study [22]. Somkuwar et al. [23] analyzed 23 esters. Concentrations ranged from 0 μg·l^{-1} (ethyl ester hexanoic acid [ethyl caproate] in Merlot and Caladoc) to 27300 μg·l^{-1} (isoamyl lactate in Nielluccio wine). The highest concentrations were determined for isoamyl lactate; butanedioic acid, diethyl ester [diethyl succinate]; propanoic acid, 2-hydroxy-, ethyl ester [ethyl lactate]; 4-decenoic acid, ethyl ester, (Z)-. In our study, the highest concentrations were determined for ethyl acetate, 3-methyl-1-butyl acetate (isoamyl acetate), diethyl succinate (clorius) and ethyl lactate (actylol). In both studies, diethyl succinate and ethyl lactate were determined as two of the dominating esters in red wines [23].

Alcohols

Alcohols are the products of the degradation of lipids, amino acids and carbohydrates [9]. Their high concentration can negatively impact the wine taste due to their intensive smell overpowering the aroma of wine [24]. It is also related to a vegetal, bell pepper aroma of aged red wine [8]. In our study, we determined high concentrations of 1-hexanol in both the red and white wines, which can contribute to an undesirable herbaceous flavor [30]. We identified 29 alcohols in the red wines and 15 alcohols in the white wines. In both red and white wines, the highest concentrations were determined for 2-methyl-1-propanol (isobutanol), 3-methyl-1-butanol (isoamylol), 1-hexanol and 2-phenylethanol. Wang et al. reported that 2-phenylethanol contributes to rose notes in Grenache and Calkarasi rose wines [27]. We found it to be at high concentrations in our samples, but they did not have a rose aroma. Qian et al. (2022) analyzed 21 alcohols in Chinese Cabernet Sauvignon wines. The highest concentrations were determined for isopentanol (233480 μg·l^{-1}), isobutanol (41740 μg·l^{-1}), 2-phenylethanol (38560 μg·l^{-1}), 1-butanol (2570 μg·l^{-1}) and 1-hexanol (2540 μg·l^{-1}). Isopentanol, isobutanol, 2-phenylethanol and 1-hexanol were also determined at highest concentrations in Polish wines produced from Cabernet Cortis and combination of Cabernet Dorsa, Zweigelt, Rondo and Regent, but their concentrations were significantly lower than in Chinese wines. 1-Butanol concentration was low in the Polish wines (Table 1). The lowest concentration was determined for 2-nonanol (0.70 μg·l^{-1}) and was slightly higher in the Polish wines [22]. Fandiño et al. [7] determined 11 alcohols in Albariño wine. The highest concentrations were obtained for 2- and 3-methyl-1-butanol (51100 μg·l^{-1}), 2-phenylethanol (16027 μg·l^{-1}), 2-methyl-1-propanol (3295 μg·l^{-1}). In our study, the results obtained for those alcohols in the Polish white wines were lower and 2-methyl-

1-butanol was not analyzed. The lowest concentrations were determined for 1-octanol (129 $\mu g \cdot l^{-1}$), comparable to 1-octanol concentration determined in the Polish white wines (Table 1) [7]. Lan et al. [15] determined nine alcohols in sweet Petit Manseng wine. The highest concentrations were determined for 2,3-butanediol (267447.2 $\mu g \cdot l^{-1}$), phenylethanol (10845.4 $\mu g \cdot l^{-1}$) and isoamyl alcohol (96875.7 $\mu g \cdot l^{-1}$). Concentrations for all these three alcohols were lower in the Polish white wines. Isoamyl alcohol had the highest alcohol concentration in the Polish white wines (Table 1). The lowest concentration was determined for 3-mercaptohexanol (3.6 $\mu g \cdot l^{-1}$), which was not analyzed in the Polish white wines [15].

Carbonyl compounds

Carbonyl compounds can contribute to a richer and more unique wine aroma [9]. We determined 12 carbonyl compounds in the red wines, but only two in the white wines. Benzaldehyde, acetaldehyde and furfural were determined to occur at the highest mean concentrations in the red wines, furfural and 3,5-dimethylbenzaldehyde were the only carbonyl compounds that were found in the white wines. Only one red wine sample contained 2-octanone, nonanal, 2-tert-butyl-5-propyl-1,3-dioxolan-4-one, trans-3-methyl-4-octanolide and 5-butyl-4-methyloxolan-2-one (Whiskey lactone). The distinguishing mark of this wine sample is its rowanberry and cranberry aromas, characteristic to only this one wine in our study. Issa-Issa et al. [13] determined five aldehydes and ketones (furfural, benzaldehyde, vanillin, acetoin and 2(5H)-furanone) and three lactones (γ-butyrolactone, whiskey lactone and pantolactone) in Fondillón wine. Five of these compounds were determined in both Fondillón and the Polish red wines – furfural, benzaldehyde, acetoin, γ-butyrolactone and whiskey lactone. Acetoin and γ-butyrolactone concentrations were significantly lower in the Polish red wine than in Fondillón, furfural and whiskey lactone were lower in the Polish red wine than in Fondillón, and benzaldehyde concentration was higher in the Polish red wine than in Fondillón (Table 1) [13]. Qian et al. [22] analyzed four carbonyl compounds – acetoin, benzaldehyde, benzeneacetaldehyde and decanal, and two lactones – trans-Whiskey lactone and cis-Whiskey lactone, in Chinese Cabernet Sauvignon wines. Carbonyl compounds concentrations ranged from 2.48 $\mu g \cdot l^{-1}$ (decanal) to 2470 $\mu g \cdot l^{-1}$ (acetoin) and lactones were not determined before the aging process. Acetoin and benzaldehyde were also determined in the Polish wines produced from Cabernet Cortis and a combination of Cabernet Dorsa, Zweigelt, Rondo and Regent – acetoin at significantly lower concentrations and benzaldehyde at higher concentrations (Table 1) [22]. Zhao et al. [31] determined five aldehydes and ketones – 3,7-dimethylnona-2,6-dienal, 3-furaldehyde, 1,3-dioxolane-4-methanol, 2-methyl-3-octanone and 2-octanone, at concentrations from 4.58 to 41.47 $\mu g \cdot l^{-1}$, in litchi wine. Out of all these five compounds, only one was also determined in our study – 2-octanone in one red wine sample. The concentration was very similar to the one obtained for 2-octanone in litchi wine (10.91 $\mu g \cdot l^{-1}$) (Table 1) [31].

Norisoprenoids

Norisoprenoids, such as ß-ionone, ß-damascenone, vitispirane and TDN, are important compounds that can influence the wine aroma [8]. We determined only one norisoprenoid in this study – ß-damascenone, and only in one sample of red wine at the concentration of 54.43 $\mu g \cdot l^{-1}$. It could be related to seasonal changes of the weather, temperature in Poland, and could result from a shorter period of time during which grapevines were exposed to the sunlight, which could lead to a lower carotenoids concentration in vines, which are believed to be precursors to C_{13} norisoprenoids. Its low concentration could confirm the relationship between the Polish climate and viticulture. It also confirms that the quality of wine is connected with "terroir", a set of characteristics of a given place, its geographic, geological and climatic impact, which, when combined with plant genetics, influence grape-derived products [1]. Longo et al. [17] determined concentrations of 3 C_{13}-norisoprenoids – α-ionone, β-ionone and β-damascenone. The concentrations ranged from 0.04 (β-ionone in wine from Southern Tasmania) to 1.41 $\mu g \cdot l^{-1}$ (β-damascenone in wine from Northern Tasmania). Two of these compounds were not tested in our research, only β-damascenone was determined in one sample and at higher concentrations than in the wine from Northern Tasmania [17]. Qian et al. [22] analyzed five norisoprenoids – β-damascenone, riesling acetal, vitispirane A, vitispirane B and TDN in Chinese Cabernet Sauvignon wines. Their concentrations ranged from 0.47 $\mu g \cdot l^{-1}$ (vitispirane B) to 1.85 $\mu g \cdot l^{-1}$ (β-damascenone). Norisoprenoids were not analyzed in the Polish wines produced from Cabernet Cortis and a combination of Cabernet Dorsa, Zweigelt, Rondo and Regent [22].

Terpenoids and other compounds

The next group of compounds analyzed in the Polish wines were terpenoids, which can contribute to a flower aroma of wine [8]. Terpenoids were determined in all the samples of the white wines, with the total concentrations of all terpenoids per sample in the range of 95.73 to 648.20 $\mu g \cdot l^{-1}$ and a mean value of 206.14 $\mu g \cdot l^{-1}$, however, they were determined in only five samples of the red wines, with the total concentrations in the range of 7.04 to 235.29 $\mu g \cdot l^{-1}$ and a mean value of 80.86 $\mu g \cdot l^{-1}$, hence at lower mean concentrations than in the white wines. Terpineol was determined only in the red wines. Moreover, we determined ethers, phenols, sulfur compounds and hydrocarbons in the red wines, and phenols and sulfur compounds in the white wines. Phenols, especially anthocyanins, can be used as markers to characterize different grape varieties [26]. High concentrations of 2-phenylethyl alcohol and 2-phenylethyl acetate can contribute to a floral/perfumed aroma [24]. The samples with the highest concentration of 2-phenylethyl acetate did not have a floral aroma. 2-Phenylethanol was found in every red and white wine sample at high concentrations. Feng et al. [9] reported that 3-methyl-butanol, 3-hydroxy-butanone 2,3-butanediol, phenylethanol, hexanol, aldehyde and nonanal contributed to green, floral and fruity aromas in mulberries. We determined high concentrations of 3-methyl-butanol and 2,3-butanediol in red and white wine samples. Somkuwar et al. [23] analyzed four phenols and five terpenes. Phenols concentrations ranged from 0 $\mu g \cdot l^{-1}$ (2-methyl-phenol in Cabernet Franc) to 1530 $\mu g \cdot l^{-1}$ (2-methoxy-4-vinylphenol in Grenache). Terpenes concentrations ranged from 0 $\mu g \cdot l^{-1}$ (α-terpinene in Petit Verdot, Cabernet Sauvignon, Tempranillo and Caladoc, terpinolen in Cabernet Franc, Cabernet Sauvignon and Caladoc, D-limonene in Cabernet Sauvignon, Tempranillo, Merlot and Caladoc) to 24840 $\mu g \cdot l^{-1}$ (1,4-cyclohexadiene, 1-methyl-4-(1-methylethyl)-[γ-Terpene] in Nielluccio). In our study, we also determined phenols and terpenoids, but different than the ones determined by Somkuwar et al. [23], therefore results cannot be compared. Qian et al. [22] analyzed nine terpenes and 25 phenols and phenolic aldehydes in Chinese Cabernet Sauvignon wines. Terpenes concentrations ranged from 0.053 $\mu g \cdot l^{-1}$ (cis-rose oxide) to 589.10 $\mu g \cdot l^{-1}$ (geranylacetone). In our study, we determined two terpenes in the Polish wines produced from Cabernet Cortis and from a combination of Cabernet Dorsa, Zweigelt, Rondo and Regent – linalool at higher concentrations (1.05 $\mu g \cdot l^{-1}$ in Chinese wines) and citronellol at similar concentrations (5.00 $\mu g \cdot l^{-1}$ in Chinese wines) (Table 1). Phenols and phenolic aldehydes concentrations ranged from 0.90 (4-propylguaiacol) to 1950 $\mu g \cdot l^{-1}$ (4-vinylphenol). One phenol, 4-ethylphenol, was determined in both the Polish and Chinese wines at similar concentrations (16.99 $\mu g \cdot l^{-1}$ in Chinese wines) (Table 1) [22]. Zhao et al. [31] determined 14 terpenes in litchi wine. Their concentrations ranged from 6.54 $\mu g \cdot l^{-1}$ ((1S)-(1)-beta-pinene) to 5662.18 $\mu g \cdot l^{-1}$ (D-citronellol). Cis-rose oxide, citronellol and linalool were determined in both studies, concentrations in the Polish wines were lower than in litchi wine. Nerol oxide was determined in both studies at comparable concentrations (Table 1) [31]. Issa-Issa et al. [13] determined four phenolic compounds in Fondillón – guaiacol, phenol, ethyl guaiacol and 4-ethylphenol. Two of them were also found in the Polish red wines – 4-ethylphenol was determined at higher concentrations in the Polish red wine, ethyl guaiacol was determined at comparable concentrations (Table 1) [13]. Fandiño et al. [7] determined two terpenes – nerol and hotrienol and one phenol – 4-vinylguaiacol in Albariño wine. The concentrations ranged from 18 to 109 $\mu g \cdot l^{-1}$. None of those compounds were analyzed in the Polish white wines. Lan et al. [15] determined three phenols – 4-vinylguaiacol (2917 $\mu g \cdot l^{-1}$), eugenol (12 $\mu g \cdot l^{-1}$) and guaiacol (5 $\mu g \cdot l^{-1}$) in sweet Petit Manseng wine, they were not analyzed in the Polish white wines.

Odor activity values in Polish wines

Odor activity value (OAV) is calculated as a ratio of determined concentrations of a compound and its odor detection threshold (ODT). The higher odor activity value of a compound is, the bigger influence that compound has on the aroma profile of wine [29]. Odorants that occur at concentrations higher than their ODT values, meaning OAV > 1, contribute to the wine aroma and are called aroma impact compounds [31]. We calculated OAVs for 41 volatile compounds – four acids, 12 alcohols, 14 esters and 11 other compounds (Table 2).

Table 2. Odor description, threshold and activity value (OAV) of compounds determined in Polish white and red wines

Tabela 2. Opis zapachu, próg zapachowy i wartość aktywności zapachowej związków oznaczonych w polskich białych i czerwonych winach

Compound / Związek	Odor description* / Opis zapachu*	Odor threshold* / Próg zapachowy [µg·l^{-1}]	White wines (n = 18) / Białe wina (n = 18)	Red wines (n = 13) / Czerwone wina (n = 13)
			Min – Max; Mean / Min – Maks; Średnia	Min – Max; Mean / Min – Maks; Średnia
Acids / Kwasy				
hexanoic / heksanowy	Cheese, rancid, fatty, sweat, barbecue / Ser, zjełczały, tłusty, pot, grill	420.00	< 0.01 – 1.09; 0.69	0.29 – 0.76; 0.52
octanoic / oktanowy	Cheese, rancid, fatty, sweat / Ser, zjełczały, tłusty, pot	500.00	0.85 – 1.84; 1.37	0.30 – 1.29; 0.68
decanoic / dekanowy	Rancid, fatty / Zjełczały, tłusty	1000.00	0.02 – 0.21; 0.08	0.01 – 0.08; 0.03
acetic / octowy	Vinegar / Ocet	200000.00	< 0.01	< 0.01
Alcohols / Alkohole				
1-pentanol / 1-pentanol	Alcohol, pungent, almond, synthetic, balsamic / Alkohol, gryzący, migdał, syntetyczny, balsamiczny	80000.00	< 0.01	< 0.01
2,3-butanediol / 2,3-butanodiol	Fruity / Owocowy	150000.00	< 0.01	< 0.01
3-methyl-1-pentanol / 3-metylo-1-pentanol	Wine, herbaceous, cacao / Wino, zielny, kakao	50000.00	< 0.01	< 0.01
3-hexen-1-ol / 3-heksen-1-ol	Grass, herbaceous, green, fatty, bitter / Trawa, zielny, zielony, tłusty, gorzki	70.00	0.06 – 0.39; 0.19	0.10 – 0.55; 0.28
1-hexanol / 1-heksanol	Resin, floral, green, cut grass, herbaceous, wood / Żywica, kwiatowy, zielony, święta trawa, zielny, drewno	8000.00	0.04 – 0.12; 0.08	0.07 – 0.20; 0.13
1-octen-3-ol / 1-okten-3-ol	Mushroom / Grzyb	18.00	< 0.01	< 0.01 – 0.74; 0.47
2-ethyl-1-hexanol / 2-etylo-1-heksanol	Rose, green, floral / Róża, zielony, kwiato-wy	900.00	0.01 – 0.12; 0.04	< 0.01 – 0.25; 0.08
1-octanol / 1-octanol	Jasmine, lemon / Jaśmin, cytryna	110.00	0.06 – 0.40; 0.22	0.27 – 0.50; 0.38
2-phenylethanol / 2-fenyloetanol	Rose, floral, honey, pollen, perfume / Róża, kwiatowy, miód, pyłek, perfumowy	1100.00	0.32 – 1.25; 0.69	0.59 – 1.83; 1.07
1-nonanol / 1-nonanol	Rose, orange / Róża, pomarańcz	50.00	< 0.01	< 0.01 – 0.56; 0.34
3-methyl-1-butanol / 3-metylo-1-butanol	Wine, solvent, bitter / Wino, rozpuszczal-nik, gorzki	7000.00	0.45 – 0.94; 0.67	0.60 – 1.02; 0.83
3-methyl-3-buten-1-ol / 3-metylo-3-buten-1-ol	Apple / Jabłko	600.00	< 0.01	< 0.01 – 0.01; 0.01
Esters / Estry				
ethyl butanoate / butanian etylu	Apple, banana, pineapple, strawberry, fruity, sweet / Jabłko, banan, ananas, truskawka, owocowy, słodki	20.00	1.88 – 7.08; 3.35	1.06 – 4.58; 2.16
ethyl lactate / mleczan etylu	Acid, medicine, lactic / Kwas, leki, mleczny	154636.00	< 0.01	< 0.01

ethyl 2-methylbutanoate / 2-metylobutanian etylu	Fruity, green apple, anise / Owocowy, zielone jabłko, anyż	18.00	< 0.01	< 0.01 – 10.33; 5.93
ethyl 3-methylbutanoate / 3-metylobutanian etylu	Fruity, banana / Owocowy, banan	3.00	< 0.01	< 0.01 – 28.80; 11.90
3-methyl-1-butyl acetate / octan 3-metylo-1-butylu	Banana, pineapple, strawberry / Banan, ananas, truskawka	200.00	1.96 – 8.18; 5.13	< 0.01 – 6.25; 3.14
methyl hexanoate / heksanian metylu	Pineapple / Ananas	70.00	0.03 – 0.46; 0.19	< 0.01 – 0.15; 0.13
ethyl hexanoate / heksanian etylu	Apple, green apple, fruity, banana, wine, brandy / Jabłko, zielone jabłko, owocowy, banana, wino, brandy	14.00	11.21 – 33.12; 20.51	< 0.01 – 18.73; 10.76
hexyl acetate / octan heksylu	Grape, apple, pear, floral, green, cherry, anise / Winogrono, jabłko, gruszka, kwiatowy, wiśnia, anyż	670.00	< 0.01 – 0.23; 0.07	< 0.01 – 0.01; 0.01
diethyl succinate / bursztynian dietylu	Wine, fruity, cheese, earthy, spicy / Wino, owocowy, ser, ziemny, przyprawy	1200.00	< 0.01 – 0.47; 0.18	0.10 – 0.99; 0.42
ethyl octanoate / oktanian etylu	Sweet, floral, fruity, banana, pear, brandy, pineapple / Słodki, kwiatowy, owocowy, banan, gruszka, brandy, jabłko	250.00	0.66 – 3.05; 1.48	0.31 – 1.31; 0.86
2-phenethyl acetate / octan 2-fenetylu	Floral / Kwiatowy	250.00	0.05 – 0.69; 0.25	< 0.01 – 0.47; 0.16
ethyl decanoate / dekanian etylu	Pineapple, floral, fruity, fatty, pleasant / Ananas, kwiatowy, owocowy, tłusty, przyjemny	200.00	< 0.01	< 0.01 – 0.07; 0.04
ethyl acetate / octan etylu	Pineapple / Ananas	7500.00	0.11 – 0.20; 0.15	0.18 – 0.32; 0.24
isobutyl acetate / octan izobutylu	Fruity, apple, banana / Owocowy, jabłko, banan	1600.00	< 0.01	< 0.01 – 0.01; 0.01
Other compounds / Pozostałe związki				
furfural / furfural	Caramel / Karmel	3000.00	< 0.01 – 0.02; 0.01	< 0.01 – 0.04; 0.02
benzaldehyde / benzaldehyde	Sweet, fruity, roasted, almond, fragrant, burnt sugar / Słodki, owocowy, pieczony, migdał, pachnący, palony cukier	350.00	< 0.01	< 0.01 – 1.47; 0.55
nonanal / nonanal	Fatty, citrus, green, fruity / Tłusty, cytrus, zielony, owocowy	1.00	< 0.01	< 0.01 – 7.10; 7.10
linalool / linalol	Floral, citrus, sweet, grape, fresh / Kwiatowy, cytrus, słodki, winogrono, świeży	15.00	0.76 – 7.95; 3.46	< 0.01 – 14.24; 7.59
citronellol / cytronelol	Clove, rose / Goździk, róża	100.00	< 0.01 – 0.23; 0.07	< 0.01 – 0.07; 0.06
nerol oxide / tlenek nerolu	Rose, oil, floral / Róża, olejek, kwiatowy	6000.00	< 0.01 – 0.03; 0.01	< 0.01
β-damascenone / β-damascenon	Apple, smoky, toasted bread, clove, woody / Jabłko, dymny, pieczony chleb, goździk, drewno	0.50	< 0.01	< 0.01 – 108.86; 108.86
cis-rose oxide / tlenek cis-róży	Rose, floral / Róża, kwiatowy	20.00	< 0.01 – 0.85; 0.44	< 0.01
α-terpineol / α-terpineol	Fruity, floral / Owocowy, kwiatowy	250.00	0.04 – 0.37; 0.14	< 0.01
2-octanone / 2-oktanon	Hot milk, peanut, green / Gorące mleko, orzeszki ziemne, zielony	250.00	< 0.01	< 0.01 – 0.04; 0.04
whiskey lactone / lakton whisky	Fruity, cocoa / Owocowy, kakao	6.00	< 0.01	< 0.01 – 2.14; 1.56

Explanatory notes / Objaśnienia:
* odor description and odor threshold values / opis zapachu i wartości progów zapachowych [28, 31].

We determined OAVs above 1 for 15 compounds, seven of them were found in both white and red wines, one extra in the white wines and seven extra in the red wines. The results obtained showed differences between the wines, taking into account their color. OAVs of ethyl butanoate were higher than 1 in all 31 analyzed wine samples and OAVs of 3-methyl-1-butyl acetate and ethyl hexanoate were higher than 1 in all 18 analyzed white wine samples. For the white wines, the highest OAVs were calculated for ethyl hexanoate, 3-methyl-1-butyl acetate and ethyl butanoate, for the red wines – β-damascenone, ethyl 3-methylbutanoate and ethyl hexanoate. All these odorants have fruity aromas, just like almost all wines we analyzed in this study.

As presented in Figure 2 and 3, the Polish wines were characterized mainly by the fruity, floral, fatty and sweet odors (Fig. 2 and 3) and to a lesser extent by other aromas, like herbaceous, spicy, roasty, earthy and caramelized (Fig. 2). Moreover, to visually present aroma fingerprints and show similarities between the aromas of the Polish wines, we presented the highest and mean OAVs in the form of an aroma wheel, which confirms the predominance of fruity aromas (Fig. 3).

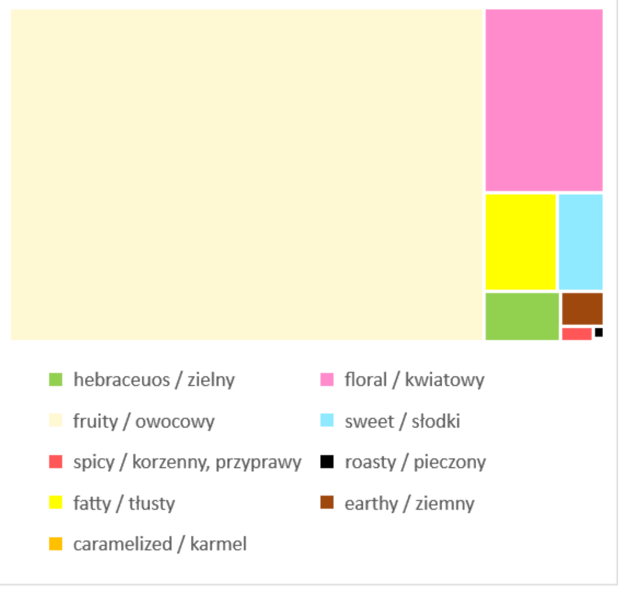


Fig. 2. Aroma map in Polish wines based on OAVs for 41 volatile compounds (as the sum of the average values for a given aroma)

Rys. 2. Mapa aromatów w polskich winach na podstawie wartości OAVs dla 41 związków lotnych (jako suma wartości średnich dla danego aromatu)

Fig. 3. OAV aroma wheel for the average and highest values of OAVs of analyzed compounds in Polish wines

Rys. 3. Wykres koła zapachowego OAV dla średnich i najwyższych wartości OAV analizowanych związków w polskich winach

Conclusions

1. VOC profiles of the Polish wines were presented mostly by esters (32), alcohols (28), volatile acids (14) and carbonyl compounds (13). Minor occurrence was determined for terpenoids (7), volatile phenols (3), ethers (2), volatile sulfur compounds (2), hydrocarbons (1) and norisoprenoids (1).
2. According to the type of wine, we determined 94 volatile compounds in 13 red wines and 53 volatile compounds in 18 white wines. Not all analyzed compounds were determined in every wine sample.
3. The odor activity values (OAVs) were calculated for 41 odorants and 15 of them had values above 1. Based on the determined OAVs, it was observed that the most characteristic aromas in all the wines were as follows: first of all – fruity, next – floral, and finally – fatty and sweet.
4. The results obtained show the difference in wine composition between the white and red wines, the influence of grape varieties used and confirm that the quality of wine is connected with "terroir", a set of characteristics of a given place, its geographic, geological and climatic impact.

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CHARAKTERYSTYKA PROFILU LOTNYCH ZWIĄZKÓW ORGANICZNYCH W POLSKICH WINACH PRZY WYKORZYSTANIU GC-MS

S t r e s z c z e n i e

Wprowadzenie. Wino jest skomplikowaną mieszaniną wielu związków o zróżnicowanej budowie i właściwościach. Wiele czynników wpływa na chemiczny skład wina. Uprawa winorośli w Polsce jest w niekorzystnej, trudniejszej sytuacji, w porównaniu do bardziej tradycyjnych regionów winiarskich. Winogrona rosnące w Polsce mają niższą zawartość cukru, co prowadzi do niższej zawartości alkoholu i wyższej kwasowości wyprodukowanego wina, co może być także uznawane za zaletę. Związki aromatyczne, które są przedmiotem badania, razem z innymi czynnikami, wpływają na smak i aromat wina.

Wyniki i wnioski. Praca prezentuje wyniki analizy i charakterystyki profilu aromatycznego polskich win, wykonanej z użyciem chromatografii gazowej ze spektrometrią mas (GC-MS). Wykryliśmy 94 związki lotne w 13 czerwonych winach i 53 lotne związki w 18 białych winach, w tym następujące grupy związków: alkohole, kwasy, estry, związki karbonylowe, etery, terpenoidy, norisoprenoidy, fenole, związki siarkowe i węglowodory. Wina były wyprodukowane z różnych odmian winogron. Porównanie otrzymanych wyników, zarówno pomiędzy wynikami otrzymanymi w naszym badaniu, a także z wynikami otrzymanymi w innych badaniach, pokazało różnice w składzie win, w oparciu o różne czynniki. Wartości aktywności zapachowej (OAV) zostały obliczone by określić dominujący aromat analizowanych win, im wyższa wartość aktywności zapachowej danego związku, tym większy jest jego wpływ na aromat wina.

Słowa kluczowe: GC-MS, współczynnik aktywności zapachowej, polskie wina, lotne związki