

CHARACTERISTICS OF WINE DISTILLATES PRODUCED IN KUTJEVO REGION, CROATIA

M. BANOVIĆ^{a*}, B. MILIČEVIĆ^b, K. KOVAČEVIĆ GANIĆ^a and D. KOMES^a

^a Faculty of Food Technology and Biotechnology, University of Zagreb, Pierottijeva 6, 10001 Zagreb, Croatia

^b Zvečevo dd, Food Industry, Kralja Zvonimira 1, 34000 Požega, Croatia

(Received: 16 May 2003; accepted: 26 January 2004)

The prospects of quality young wine distillates production have been examined. The base wine was produced from *Vitis vinifera* L. quantitatively dominating grape varieties within the group of the recommended and permitted varieties of Kutjevo vineyards, located in the eastern part of the continental Croatia. Characterisation of wine and distillates was based on chemical and instrumental methods and on their sensory evaluation. Volatile compounds were analysed and identified by GC-FID and GC-MS. The wine varieties Rhine Riesling, Müller Thurgau and Riesling have the potential for the production of quality distillates, suitable for maturation. Pinot White, Traminer and Chardonnay give more acceptable wines than distillates and it is therefore not advisable to use them for distillates production, while the varieties Pinot Gris, Frankovka and Steinschiller are not suitable for the production of distillates.

Keywords: aroma, Kutjevo region, sensory evaluation, wine, wine distillate

The quality of young wine distillates depends on numerous factors, the most significant being the environment in which the grapes are grown, grape variety, grape maturity, fermentation processes and distillation condition. Wines submitted for distillation have to be produced with vinification without any skin maceration if obtained from red skin varieties, possibly from univarietal floral grape not fully ripened, being without residual sugars and with not too high acidity (LAFON et al., 1958). The distinctive aroma of wines and distillates derives mostly from small concentrations of numerous aromatic compounds, including higher alcohols, esters, acids, aldehydes, acetals, ketones, lactones and monoterpenes (LILLY et al., 2000). There are also compounds (e.g. long-chain fatty acid ethyl esters) that, despite their presence in large concentrations, do not possess intensive aroma features and probably do not contribute directly to brandy aroma, but may impact the perception of the organoleptic complexity (EBELER et al., 2000). It is difficult to make an objective evaluation of the quality of distillates because of their complexity and it is therefore necessary to use chemical, instrumental and sensory analytical methods. LABLANQUIE and co-workers (2002) studied the aroma of young cognac spirit in order to identify some odour markers, because limited information is available on sensory quality formation of this product.

* To whom correspondence should be addressed.
Fax: 00385 1 4605072; e-mail: mbanovic@pbf.hr

During distillation, many types of reactions may occur between the compounds of boiling mixtures. The reactions are numerous (hydrolysis, esterification, acetalization, reactions with copper and Maillard reactions); for this reason, the double distillation technique is advisable. The reactions, which occur during the first distillation, are the most important ones. The amount of the volatile compounds already present in the wine may increase or decrease depending on the types of reactions they are involved in. These reactions are the functions of wine characteristics (the use of lees, pH and acidity), the size of pot still, the temperature generated by the gas burner under the boiler, duration of distillation and cleaning of the pot still (LEAUTE, 1990).

The aim of the study was to examine the possibility of producing distillates from wines made of *Vitis vinifera* L. grape varieties, which are the recommended and permitted varieties from Kutjevo vineyards. The presented characteristics of nine distillates and the selection of three varieties, suitable for the production of distillates, are based on chemical, instrumental and sensory evaluations.

1. Materials and methods

1.1. Base wine production

The base wines are produced from the grapes, appertaining to the following *Vitis vinifera* L. varieties, vintage 2000: Riesling, Pinot white, Pinot gris, Chardonnay, Rhine Riesling, Traminer, Müller Thurgau, Frankovka and Steinschiller obtained from Kutjevo region, located in the eastern part of the continental Croatia. In the cellar of "Kutjevački podrumi", wines are produced using classical technological procedure; fermentation with autochthonous yeast and controlled thermal regime. The samples of young wines were taken at the end of fermentation and before filtration and the wines were slightly dull from fermentation lees.

1.2. Distillation

Distillation of base wine was carried out according to the procedure shown in Fig. 1. Copper still was used. The initial volume of base wine was 75 l. Two distillates of each wine were produced (D_1 , D_2). The distillation process itself took place in two stages. In the first stage, the wines were distilled immediately after fermentation with a partial racking from fermentation lees. In that phase, three distillate fractions were separated; head, heart and tail. For the second distillation phase, only the previously separated heart fraction was used. During the second distillation, the middle fraction of heart 1 was first separated and its accumulation began when the alcohol content in the distillate was 75% (v/v) and lasted until the alcohol amount was reduced to 60% (v/v). The distillate containing approximately 70% (v/v) alcohol was obtained as a final product. Following distillation, the distillates were stored refrigerated in glass bottles with Teflon-lined cap until analysis.

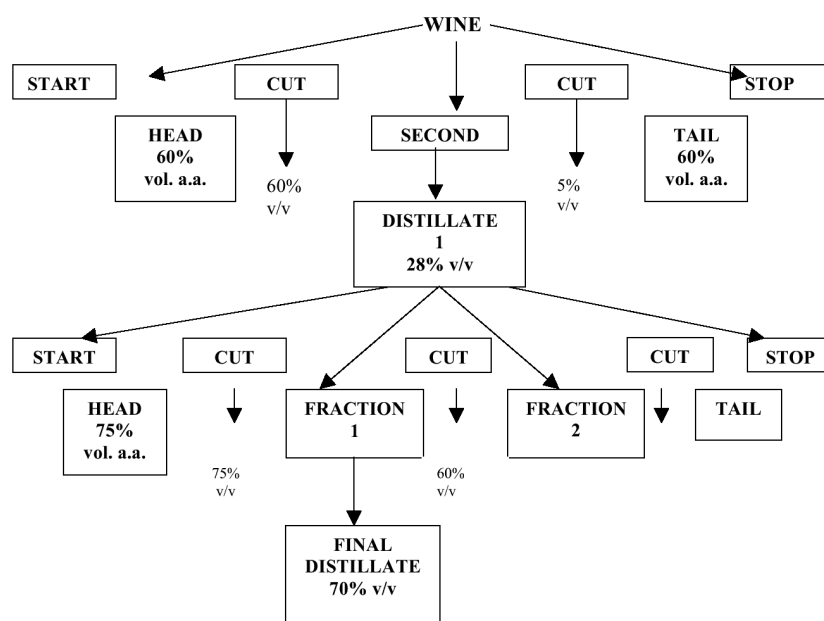


Fig. 1. Wine distillation procedure

1.3. Chemical analysis of base wine and distillates

General wine and distillate composition was determined according to OUGH and AMERINE (1988) and Official Methods of Analysis of A.O.A.C. International (A.O.A.C., 1995).

1.4. Sensory evaluation

Sensory evaluation of base wine samples was performed before distillation, while wine distillates were evaluated one week after their production. All the evaluations were made by the panel of ten trained judges. The sensory evaluation of wine samples was carried out by the modified Buxbaum model of positive rating (BUXBAUM, 1951). The model was developed on sensory characteristics (colour, odour, taste) and rated by the maximum of 18 points. The sensory evaluation of wine distillate samples was conducted in compliance with the method of positive rating according to the German DLG model (KOCH, 1986). This model was developed on four sensory characteristics (colour, clearness, odour, taste) marked with grades from zero to five, including zero, while the average grade was multiplied by the weighing factor.

1.5. Analysis of aroma compounds

1.5.1. Static headspace. Static headspace technique was used for the extraction of the volatile compounds from the base wine samples. A sample of wine (5 ml), KCl (3 g), and the internal standard *n*-amyl alcohol (188 mg l⁻¹) were added to a 20 ml vial sealed with 19 mm butyl/PTFE septum and 20 mm aluminium open capsule. A headspace autosampler (Hewlett Packard 7694) connected to a GC (Hewlett Packard 5890) was used for analysis. The sampler was equipped with 1 ml injection loop and a transfer liner directly connected to the injector of the chromatograph. The vials were kept at 80 °C for 10 min. The injection loop was heated up to 90 °C and the transfer liner up to 110 °C. The injection conditions in the GC were: 0.1 min time for vial pressurization; 0.05 min for vial equilibrium; 2 min for sample injection. Nitrogen was used for vial pressurization up to 17 psi and as a carrier gas to transport the sample from the headspace with a flow rate of 8.5 ml min⁻¹.

1.5.2. Chromatographic methods. Analysis were done on a Hewlett Packard 5890 gas chromatograph series II equipped with flame ionization detector (FID). Compounds were separated on a Stabilwax capillary column (30 m×0.25 µm i.d., 0.25 µm; Restec, USA). Nitrogen was used as a carrier gas at the flow rate of 5 ml min⁻¹. A split/splitless injector was used (ratio 1:6) and maintained at 180 °C. The detector was kept at 250 °C. The oven temperature for base wine samples was programmed as follows: 35 °C (7 min) to 80 °C at 10 °C min⁻¹, then raised to 200 °C at 25 °C min⁻¹ and 4 min at 200 °C. The internal standard *n*-amyl alcohol (74 mg l⁻¹) was added directly to the distilled samples and injected into the gas chromatograph (injection volume of 1 µl). Temperature programme for distillate samples was: 4 min at 30 °C, from 30 to 100 °C at 15 °C min⁻¹, to 200 °C at 25 °C min⁻¹ and 7 min at 200 °C. The same conditions were applied for the GC-MS analysis on a Hewlett-Packard 5890 gas chromatograph with a 5970 series mass selective detector. The ionization of the samples was achieved at 70 eV under the SCAN mode. The mass range studied was from 30 to 250 m/z. Carrier gas was helium 5.0 (purity 99.999%; Messer, Austria) at a flow rate of 5 ml min⁻¹. The constituents were identified by comparing retention times and MS spectra of the pure standard substances. The MS spectra were also compared with the data from NBS75K library spectra. All the analyses were carried out in triplicate for each sample. Concentrations of volatile compounds were calculated using internal standard *n*-amyl alcohols and expressed as the means of triplicate analytical assays.

1.6. Statistical analysis

Statistical differences between the results for wines and those for distillates were determined by applying the standard analysis of variance (ANOVA) and Duncan's multiple range test (MONTGOMERY, 1984). For data processing, Microsoft Excel 2000 programme was used.

2. Results and discussion

The results of the chemical analysis of base wine samples are shown in Table 1 and for distillate samples in Table 2. From the results shown in Table 1 and Table 2, it is evident that the defined chemical properties of the base wines and produced distillates are within the reference values (NYKÄNEN & SUOMALAINEN, 1983; LEAUTE, 1990).

The results of the sensory analysis of the base wines are shown in Table 3. According to the results of the sensory evaluation, it is evident that all the young wines possess appropriate sensory characteristics. Analysis of variance and Duncan's multiple range test (MONTGOMERY, 1984) showed significant ($P < 0.05$) differences among the wines. The differences between individual wines come from different characteristics of each wine variety. The sample of wine Steinschiller was given the smallest rating, while the highest rating was given to Rhine Riesling.

The results of sensory evaluation of distillates obtained by the DLG model are shown in Table 3. The statistical analysis (ANOVA and Duncan's test) showed high significant differences ($P < 0.05$) among the produced distillates. Here, we can identify Pinot Gris as the worst and Rhine Riesling as the best grape variety, although the differences in sensory quality of the distillates were much bigger than those of the wines.

On the basis of the sensory assessment it can be concluded that the varieties Rhine Riesling, Riesling and Müller Thurgau gave quality distillates. Pinot Gris was unsuitable for the production of distillates. Distillates produced from other varieties were of mediocre quality.

Volatile compounds of base wine and distillate were identified and quantitatively determined, and the results are shown in Tables 4 and 5. The amount of acetaldehyde in base wines ranged from 10.66 to 30.77 mg l⁻¹. Acetaldehyde is a normal product of alcoholic fermentation and its amount in wine, according to literature, is within the limits ranging from 10 to 300 mg l⁻¹ (FLEET & HEARD, 1993). Higher alcohols, 1-propanol, 1-butanol, isobutyl alcohol, 1-hexanol, isoamyl alcohol and 2-phenyl ethanol were identified. 1-propanol, 1-butanol and isobutyl alcohol have high sensory threshold and thus do not affect the wine aroma considerably (LAMBRECHTS & PRETORIUS, 2000). Isoamyl alcohol is the most important aliphatic alcohol synthesised by yeasts during alcoholic fermentation. The amount of isoamyl alcohol in wines ranged from 115.55 to 389.23 mg l⁻¹. The portion and the composition of esters significantly influence the sensory characteristic of wine (RAPP, 1991). The most important acetate esters in wine are ethyl acetate and isoamyl acetate. The amount of ethyl acetate ranged from 12.27–45.33 mg l⁻¹, corresponding to data from literature (LAMBRECHTS & PRETORIUS, 2000). From the group of ethyl esters of long-chain saturated fatty acids, ethyl hexanoate, ethyl octanoate and ethyl decanoate were identified. The portion of these esters in wine is far above their sensory threshold, which is ten times lower, due to the fact that these compounds are very important for the aroma of the wine (SIMPSON & MILLER, 1984).

Table 1. Results of chemical analysis of base wine

Determined characteristics	Riesling	Pinot white	Pinot gris	Chardonnay	Rhine riesling	Traminer	Müller Thurgau	Frankovka	Stienschiller
Specific mass (20/20 °C) (g ml ⁻¹)	0.9935	0.9911	0.9914	0.9918	0.9932	0.9940	0.9903	0.9950	0.9923
Alcohol (% v/v)	11.64	10.02	11.47	11.47	11.64	11.38	10.03	11.76	11.73
Total sugar (g l ⁻¹)	3.30	2.45	2.63	3.73	3.20	3.70	2.60	3.20	2.30
Total acidity (g l ⁻¹)	5.90	5.10	5.10	6.18	6.01	4.95	5.60	6.08	4.88
pH	3.3	3.3	3.2	3.2	3.3	3.3	3.2	3.3	3.3
Total SO ₂ (mg l ⁻¹)	23.20	17.24	17.04	17.09	17.00	21.76	16.20	15.90	16.60
Total nitrogen (mg l ⁻¹)	240.30	260.50	260.00	260.00	245.30	249.00	245.20	240.50	120.00
Ash (g l ⁻¹)	1.98	1.64	1.74	1.42	1.80	1.90	1.42	2.10	1.80

* All results are averages of three measurements.

Table 2. Results of chemical analysis of distillates

Determined characteristics	Riesling	Pinot white	Pinot gris	Chardonnay	Rhine riesling	Traminer	Müller Thurgau	Frankovka	Stienschiller
Ethanol (% v/v)	70.10	70.27	70.48	70.15	70.24	70.34	70.53	70.26	69.88
Total extract (g l ⁻¹)	0.25	0.02	0.04	0.23	0.61	0.52	0.30	0.07	0.15
Total SO ₂ (mg l ⁻¹)	5.85	10.58	1.55	9.70	8.24	15.98	6.57	1.86	6.61
Total acidity (mg l ⁻¹)	253.75	195.95	100.50	189.00	199.50	265.80	159.60	96.60	303.60
Aldehydes (mg l ⁻¹ a.a.)	63.35	73.5	58.40	74.25	69.1	34.10	55.80	65.30	45.75
Total esters (mg l ⁻¹ a.a.)	524.38	430.28	347.35	301.94	395.72	600.75	384.84	422.78	462.23
Higher alcohol (mg l ⁻¹ a.a.)	1765.75	1342.83	1526.93	1389.29	1783.50	1768.24	1532.41	1898.71	1829.28
Furfural (mg l ⁻¹ a.a.)	1.23	0.98	1.60	1.67	1.19	1.34	1.56	1.29	0.87

* All results are averages of three measurements.

Table 3. Sensory analysis of base wine (Buxbaum model) and distillates (German DLG model)

Statistical parameters	Riesling		Pinot white		Pinot gris		Chardonnay		Rhine riesling		Traminer		Müller Thurgau		Frankovka		Steinschiller	
	W ^a	D ¹	W ^b	D ²	W ^c	D ³	W ^d	D ⁴	W ^e	D ⁵	W ^f	D ⁶	W ^g	D ⁷	W ^h	D ⁸	W ⁱ	D ⁹
Average	15.19	88.20	14.59	73.94	14.67	52.69	15.16	68.11	15.39	97.78	14.95	68.91	15.02	95.72	14.98	65.49	13.90	69.78
Median	15.30	88.60	14.60	73.75	14.85	52.85	15.30	69.65	15.40	98.00	15.00	69.45	15.00	95.90	15.00	66.10	14.00	70.15
SD	0.36	1.28	0.11	1.15	0.54	1.00	0.37	3.30	0.49	1.12	0.31	1.65	0.20	1.01	0.21	2.26	0.36	1.51

W: samples of base wine; D: samples of distillates; SD: standard deviation.

There is no statistically significant difference (Duncan's test, $P < 0.05$) between the samples of base wine denoted by the same letter ^{a,b,c,d,e,f,g,h,i} and between the same distillates denoted by the same letter ^{1,2,3,4,5,6,7,8,9}

Table 4. Aroma compounds in base wine samples (mg l⁻¹)

Aroma compounds	Riesling		Pinot white		Pinot gris		Chardonnay		Rhine riesling		Traminer		Müller Thurgau		Frankovka		Steinschiller	
	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D
1-Propanol	20.56		9.97		28.10		18.94		17.11		20.14		9.84		8.64		13.41	
<i>i</i> -Butanol	43.17		24.63		31.35		26.68		42.71		33.52		29.9		30.57		61.64	
1-Butanol	0.65		0.34		0.85		0.55		0.59		0.73		0.49		0.72		0.58	
<i>i</i> -Amyl alcohol	190.23		163.29		129.03		115.55		211.47		161.37		177.95		389.23		118.33	
2-Phenylethanol	32.04		17.15		43.37		55.42		35.74		15.71		38.82		38.63		53.60	
1-Hexanol	5.22		2.93		2.92		1.71		5.01		3.81		2.36		2.65		3.36	
Acetaldehyde	22.33		10.66		30.77		19.51		30.57		24.31		15.69		21.78		22.25	
Ethyl acetate	41.11		22.02		45.33		32.85		24.78		42.73		21.44		12.27		28.47	
<i>i</i> -Amyl acetate	2.74		1.22		2.45		1.82		1.29		3.12		1.68		1.45		1.56	
Ethyl hexanoate	0.95		0.87		0.76		0.43		0.67		0.32		0.91		0.49		0.72	
Ethyl octanoate	1.38		1.50		3.66		0.53		0.52		1.93		1.02		1.59		1.04	
Ethyl decanoate	1.33		0.42		0.88		0.23		0.37		0.18		0.11		0.34		0.20	
Ethyl lactate	3.86		2.69		5.98		8.74		4.34		3.56		2.98		2.33		3.09	
Linalool	0.17		0.30		0.36		0.27		0.13		0.58		0.24		0.18		0.13	

* All results are averages of three measurements; internal standard *n*-amyl alcohol (188 mg l⁻¹).

Table 5. Aroma compounds in wine distillate samples (mg l⁻¹ at 70% v/v)

Aroma compounds	Riesling		Pinot white		Pinot gris		Chardonnay		Rhine riesling		Traminer		Müller Thurgau		Frankovka		Stensschiller	
	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD
Methanol	122.03	1.37	90.83	0.37	123.85	0.87	128.45	1.08	114.10	4.62	125.85	0.14	96.25	0.87	79.10	0.05	139.08	0.28
1-Propanol	127.80	0.52	128.25	1.57	83.30	3.73	100.83	1.07	62.25	1.38	153.70	1.28	65.33	1.74	119.55	0.30	90.40	0.53
<i>i</i> -Butanol	267.45	0.74	127.38	1.02	79.48	0.36	145.60	1.89	190.00	2.76	174.60	0.27	153.88	3.31	247.28	0.73	280.28	1.99
1-Butanol	2.61	0.56	3.68	0.47	4.79	0.39	2.56	0.45	1.34	0.08	0.91	0.06	3.89	0.09	1.82	0.02	4.66	0.15
<i>i</i> -Amyl alcohol	150.48	4.70	192.17	3.47	122.13	2.38	148.56	2.70	214.88	4.74	194.98	1.62	231.45	2.223	507.29	4.42	174.82	5.09
2-Phenylethanol	13.02	0.07	14.71	0.26	13.73	0.37	14.48	0.28	19.20	2.66	12.68	0.05	18.65	0.22	19.30	0.55	10.68	1.85
Acetaldehyde	64.55	6.40	19.42	4.54	16.57	1.87	36.91	2.90	37.65	3.81	46.73	2.94	26.56	1.51	12.84	0.67	44.06	4.54
Ethyl acetate	77.39	4.90	54.85	0.85	46.22	1.47	55.25	2.85	43.70	1.37	72.98	2.71	47.99	1.18	31.97	0.74	58.34	0.93
Ethyl hexanoate	2.49	0.04	1.67	0.09	3.08	0.07	2.36	0.23	4.53	0.12	2.38	0.04	2.29	0.14	2.90	0.57	2.46	0.06
Ethyl octanoate	4.94	0.44	3.74	0.95	4.33	0.17	4.16	0.18	4.78	0.34	4.79	0.23	4.31	0.05	4.34	0.09	5.61	0.36
Ethyl decanoate	5.17	0.32	5.60	0.59	5.69	0.49	5.62	0.35	6.42	0.14	5.28	0.20	5.72	0.02	4.83	0.11	6.60	0.05
Ethyl lactate	13.23	0.13	15.56	0.09	18.51	0.11	18.51	0.79	23.11	0.19	12.50	0.03	12.02	0.05	13.72	0.07	12.67	0.15

\bar{x} : average of D1 and D2 distillation; SD: standard deviation of D1 and D2; internal standard *n*-amyl alcohol (74 mg l⁻¹).

Linalool is a compound from the group of terpenes, which does not change during alcoholic fermentation and is thus suitable for characterization of grape varieties (RAPP, 1991). The amount of linalool ranged from 0.13 to 0.58 mg l⁻¹.

Acetaldehyde is usually the major carbonyl compound in distilled beverages. It represents 90% of the total aldehyde content and its amount determined in a distillate is usually equal to the total aldehyde content reported in literature (NYKÄNEN & NYKÄNEN, 1991). In our case the amount of acetaldehyde in the distillate was between 12.26 and 69.39 mg l⁻¹. In distillation, because of the added SO₂, bound acetaldehyde may be released, causing the development of unpleasantly sharp flavour in the distillate from the first distillation, as stated by LEAUTE (1990) in his study. Distillate beverages may contain fairly large amounts of aliphatic alcohols. The odours of isobutyl alcohol, 1-propanol and isoamyl alcohol are very penetrating, so their presence can easily be detected. Aromatic higher alcohol 2-phenylethanol has a rose-like odour, so its presence in a distillate may improve the flavour to some extent. The content of 2-phenylethanol in the distillates ranged from 10.68 to 19.30 mg l⁻¹ as found in the distillate of Frankovka. The amount of methanol detected in the distillates is in compliance with the results of similar investigations (NYKÄNEN & SUOMALAINEN, 1983; GUAN & PIEPER, 1998). The amount of ethyl acetate was within the limits, 31.97–77.39 mg l⁻¹. The low amount of ethyl acetate confirms that wines have not fallen into acetic acid fermentation and that during the distillation the middle fraction has been properly separated from the first fraction in which the quantity of ethyl acetate is the largest (WILLIAMS & PIGGOT, 1983). The next group of esters which may give rise to odour characteristics in a distillate is composed of ethyl esters, like ethyl hexanoate, ethyl octanoate and ethyl decanoate. Despite their lower volatility, they are marked flavour factors in distillates because of their relatively low threshold values. Ethyl hexanoate in all the distillates was above the sensory threshold value of 0.23 mg l⁻¹. Distillates contain slightly higher amounts of ethyl octanoate than ethyl hexanoate. Average concentrations of 3.74 to 5.61 mg l⁻¹ were determined in the distillates complying with the literature data (NYKÄNEN & NYKÄNEN, 1991). The share of ethyl decanoate in the distillates ranged between 4.83 and 6.60 mg l⁻¹, the values of which are lower than those provided by the literature (NYKÄNEN & NYKÄNEN, 1991). The amount of ethyl lactate (12.02–23.11 mg l⁻¹) was considerably lower than the shares identified in the distillates of the *cognac* type, although its amount increased during the second distillation (LEAUTE, 1990).

3. Conclusions

The continental region of the Republic of Croatia is an area known for the production of quality wines, and the obtained results indicate the possibility for this region to produce distillates.

From the investigated wine varieties Rhine Riesling, Müller Thurgau and Riesling produced quality distillates, which were suitable for maturation. Pinot white, Traminer and Chardonnay gave more acceptable wines than distillates and therefore they cannot be recommended for distillate production. The varieties Pinot gris, Frankovka and Steinschiller were not suitable for distillate production.

References

- A.O.A.C. (1995): *Official Methods of Analysis of the Association of Official Analytical Chemists International*. 16th ed., Arlington.
- BUXBAUM, W. (1951): Weinbewertung nach Punkten. *Dt Weinbau*, 5, 596–603.
- EBELER, S.E., TERRIEN, M.B. & BUTZKE, C.E. (2000): Analysis of brandy aroma by solid-phase microextraction and liquid-liquid extraction. *J. Sci. Fd Agric.*, 80, 625–630.
- FLEET, G.H. & HEARD, G.M. (1993): Yeasts: growth during fermentation. -in: FLEET, G.H. (Ed): *Wine microbiology and biotechnology*. Harwood Academic Publishers, Switzerland, pp. 27–54.
- GUAN, S.H. & PIEPER, H.J. (1998): Examination of the distillation characteristics of the distillate from numerous fruit mashes using GC analysis. *Dt. Lebensm. Rundsch.*, 11, 365–370.
- KOCH, J. (1986): *Getränkebeurteilung*. Eugen Ulmer GmbH Co., Stuttgart, pp. 95–96.
- LABLANQUIE, O., SNAKKERS, G., CANTAGREL, R. & FERRARI, G. (2002): Characterisation of young cognac spirit aromatic quality. *Anal. chim. Acta*, 458, 191–196.
- LAFON, R., LAFON, J. & COUILLAUD, P. (1958): *Le cognac et sa distillation*. J.B. Bailliere et fils., Paris. pp. 23–90.
- LAMBRECHTS, M.G. & PRETORIUS, I.S. (2000): Yeast and its importance to wine aroma. A review. *S. Afr. J. Enol. Vitic.*, 21, 97–129.
- LEAUTE, R. (1990): Distillation in alambic. *Am. J. Enol. Vitic.*, 41, 90–103.
- LILLY, M., LAMBRECHTS, M.G. & PRETORIUS, I.S. (2000): Effect of increased yeast alcohol acetyltransferase activity on flavour profiles of wine and distillates. *Appl. environ. Microbiol.*, 66, 744–753.
- MONTGOMERY, D.C. (1984): *Design and analysis of experiment*. 2nd ed., John Wiley and Sons, New York, pp. 43–68, 524.
- NYKÄNEN, L. & NYKÄNEN, I. (1991): Distillated beverages. -in: MAARSE, H. *Volatile compounds in foods and beverages*. Marcel Dekker Inc., New York, pp. 547–575.
- NYKÄNEN, L. & SUOMALAINEN, H. (1983): *Aroma of beer, wine and distilled alcoholic beverages*. D. Reidel Publishing Company, Dordrecht, pp. 1–413.
- OUGH, C.S. & AMERINE, M.A. (1988): *Methods for analysis of musts and wines*. 2nd ed., John Wiley & Sons, New York, pp. 28–266.
- RAPP, A. (1991): Natural flavours of wine, correlation between instrumental analysis and sensory perception. *Fresenius J. anal. Chem.*, 337, 777–785.
- SIMPSON, R.F. & MILLER, G.C. (1984): Aroma composition of Chardonnay wine. *Vitis*, 23, 143–158.
- WILLIAMS, P.J. & PIGGOT, J.R. (1983): *The effect of distillation on grape flavour*. Ellis Horwood Limited, Chichester, pp. 27–114.