Managing extraction of colour, phenolics and aromas in Pinot noir wine production: Alternative use of grape marc

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Abstract. The aim of this study was to investigate the alternative way of making Pinot noir wine using grape marc. Results showed significantly higher alcohol content, total phenolics and tannins in Pinot noir wines made using grape marc powder. Total anthocyanins showed significant lower level in Pinot noir wines made using grape marc powder due to the limitation of available anthocyanins in grape marc, but SO_2 resistant pigments showed significant higher level. This result indicates the importance of ratio between tannins and anthocyanins on the formation of SO_2 resistant pigments in red wine. Significantly higher level of caftaric acid observed in Pinot noir wines made using grape marc powder suggested less oxidation in the resultant wines, which is likely attributed to higher content of tannins. Most of aroma compounds showed significant differences between treatments, with Pinot noir wines made using grape marc powder showing significantly lower concentration of aroma compounds associated with vegetative/green, woody, and spicy, but higher concentration of those associated with fruity. This study investigated the alternative way of using grape marc in Pinot noir winemaking, which may provide a useful tool for winemaker to manage the extraction of colour, tannins, and aromas from grape skins into wine. This could be also an alternative way of utilisation of grape marc as winery waste, especially those sourced from premium quality grapes.

1 Introduction

Pinot noir is a grape variety that can produce high quality wine, but the fermentation process can be challenging as it has thin grape skins compared to other red grape varieties [1], meaning limited colour, tannins and aroma compounds can be extracted from grape skins. It is also difficult to achieve the right balance between extracting colour and tannins from grape skins while preserving the delicate aromas and flavours. Previous studies [2,3] have reported that phenolic compounds have significant impact on wine colour, taste, and mouthfeel. The concentration and composition of phenolic compounds in red wines depend on many factors, including grape varieties, growing region, vineyard practices, and winemaking [2]. To make high quality Pinot noir wine, management of phenolic extraction is critical during winemaking.

The quality of Pinot noir wines is also largely determined by the concentration and relative abundance of volatile aroma compounds [4]. Major aroma active compounds in Pinot noir wines can be classified as grape derived terpenes and fatty acids, and fermentation derived higher alcohols and esters [5]. Grape derived aroma compounds are mainly extracted from grape skins directly. Fermentation derived aroma compounds are the most abundant in Pinot noir wines, which are produced through the yeast metabolism or enzyme activities. There are also tertiary aromas formed during wine maturation, which could be the result of oak extraction or chemical transformation of existing aroma compounds in wine [6]. The wide range of aroma compounds in Pinot noir wine is important to understand the consumers' perceived intrinsic quality, as well as, the regional differences and variations in wine styles within the region. Thus, good management of aroma compounds extraction during winemaking is also important to produce high quality Pinot noir wine.

Grape marc is a major waste of wine production, which has attracted great attention of research to explore various strategies to recycle and valorise grape marc [7]. In addition to utilisation of grape marc as compost, animal feed, or biogas production, the recovery and recycling of bioactive compounds in grape marc is the focus of the scientific community, with aim to develop technologies for efficient extraction of the high value-added compounds from the waste. This

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study aims to investigate the alternative way of making Pinot noir wine using grape marc without compromising the wine quality.

2 Materials and methods

2.1 Grapes and wines

Pinot noir grapes were hand-picked in 2019 from Lincoln University vineyard. Destemmed and crushed grapes were pressed to separate juice and grape marc. Juice yield and weight of grape marc were recorded. Part of grape marc was dried in the oven, and then ground into powder using a food blender. Four treatments were carried out in this study: Control, 750 mL of juice with 300 g of fresh grape marc; GMP100, 750 mL of juice added with 126 g of grape marc powder (GMP, dried and powdered from 300 g of fresh marc); GMP50, 750 mL of juice added with 63 g of GMP; and GMP25, 750 mL of juice added with 31.5 g of GMP. Micro-fermentation in each treatment was carried out in triplicate in 1 L Schott Bottles at 25 °C by inoculating the EC1118 yeasts (Lallemand, Blenheim, NZ). Wines were bottled at the end of alcoholic fermentation.

2.2 Analysis of oenological parameters

Total soluble solids (TSS) and the pH were measured using a refractometer (Atago Co. Ltd, Tokyo, Japan) and a pH meter (Suntex, Taiwan). Alcohol content was measured using the ebulliometer (Laboratoires Dujardin Salleron, Noizay, France). Residual sugar in wine was measured using the Rebelein method.

Total phenolics were determined using the Folin-Ciocalteau colorimetric reaction method [8] against a gallic acid standard curve (0-500 mg/L). The absorbance readings were taken at the wavelength of 765 nm.

Tannins were determined using the methyl cellulose precipitation (MCP) method [9]. Epicatechin was used to develop the calibration curve ranging from 0 to 120 mg/L. Total tannin was quantified against the epicatechin calibration curve and expressed as mg/L epicatechin equivalent. Absorbance was taken at wavelength of 280 nm.

2.3 Analysis of colour parameters

Colour parameters in resultant wines were measured using the modified Somers assay [9]. For each wine sample, four treatments were prepared according to the method, and the absorbance was measured at 280 nm, 420 nm, or 520 nm using a UV-Visible spectrophotometer (Shimadzu, Japan). Colour parameters were calculated using the formulas in the method.

2.4 Phenolic analysis by HPLC

An Agilent HPLC equipped with quaternary pump and diode-array detector (DAD) and fluorescence detector (FLD) was used. Wine samples (10 µL) were separated in an ACE 3µ C18 PFP 150 x 4.6mm column (Advanced Chromatography Technologies, Aberdeen, Scotland) which was thermostat at 20 °C. The flow rate and solvent gradient used for separation were conducted according to [10]. Chromatograms were recorded at 280 nm, 320 nm, 360 nm, and 520 nm in the DAD and corresponding to excitation at 280 nm and emission at 320 nm in the FLD. Phenolic compounds were identified by comparing their retention times and spectra with standards. Phenolic compounds were quantified by area measurements at 280 nm, 320 nm and FLD separately. Quantitative assays were achieved using external calibration curves for all standard phenolics by dissolution of the standard solution accordingly.

2.5 Aroma profiling by GC-MS

Volatile aroma compounds were analysed using three different methods to determine three groups of aroma compounds, including esters and alcohols, volatile fatty acids, and trace amount of aroma compounds [11].

Esters and alcohols were analysed by headspace solid-phase micro-extraction (HS-SPME) and gas chromatography-mass spectrometry (GC/MS). Wine samples (0.9 mL) were uploaded together with 8.06 mL of pH 3.5 acidified water, followed by 40 µL of deuterated internal standard solution and 4.5 g of sodium chloride into a 20 mL SPME vial. The samples were incubated and agitated for 10 min at 60 °C. The SPME fibre (Sigma-Aldrich, St Louis, MO, USA) was conditioned for 60 min at 60 °C. The fibre was desorbed in the injection port at 270 °C for 5 min. The GC/MS was equipped with dual columns in series: a Rtx-Wax column and a Rxi–1MS column (Restek, Bellefonte, PA, USA). The carrier gas was helium with a linear velocity of 33.5 cm/s. Splitless injection was used for the initial 3 min and then switched to a 20:1 split ratio. The GC oven temperature was held at 35 °C for 3 min, heated to 250 °C at 4 °C/min and then held for 10 min. The interface and MS source were set to 250 °C and 200 °C, respectively. The MS source was operated in electron impact (EI) mode with an ionisation energy of 70 eV.

For analysing volatile fatty acids, the helium gas flow set at a constant linear velocity of 46.8 cm/sec, and the GC oven temperature was held at 50 °C for 3 min, then increased to 240 °C at 10 °C/min, further increased to 250 °C at 30 °C/min and held for 5 min. For analysing trace amount of aroma compounds, the acquisition mode was changed to the selected ion monitoring (SIM). The GC oven temperature ramp was modified to 35 °C for 3 min, increased to 105 °C at 3 °C/min and held for 10 min, increased to 140 °C at 2 °C/min and held for 10 min, and finally increased to 250 °C at 4 °C/min and held for 10 min.

2.6 Odour activity values

The odour activity values (OAVs) for aroma compounds were calculated by dividing the concentrations of aroma compounds with their corresponding sensory thresholds from the literature [11]. Aroma active compounds (OAV>0.1) were grouped into seven aroma series (Fruity, Floral, Spicy, Chemical, Fatty/oily, Woody, Vegetative/green) based on their odour descriptors. The aroma compounds in the same aroma category were summed together and plotted in a spider web diagram.

2.7 Statistical analysis

Data represent the means ± standard deviation of three replicates and are analysed by analysis of variance (ANOVA). Least significant difference (LSD, 5% level) was used to separate means when a significant *P*-value was obtained. Statistical analysis was performed using R statistical software (R Core Team 2019, Vienna, Austria) and mixOmics package from Bioconductor.

3 Results and Discussion

3.1 Oenological parameters

Total soluble solids in grapes at harvest was measured at 24°Brix, and pH and titratable acidity (TA) were 3.2 and 9 g/L, respectively. The reduction of fermentation weight was similar between treatments (Fig. 1), with no further reduction after five days of yeast inoculation, indicating no significant difference in fermentation dynamics between treatments.

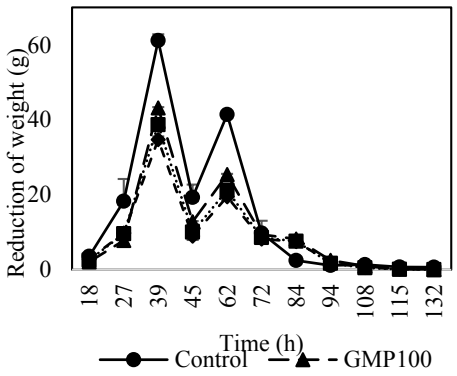

Figure 1. Reduction of ferment weight during fermentation.

At the end of alcoholic fermentation, Pinot noir wines of GMP100 and GMP50 showed significantly higher pH than control wine (Table 1), possibly due to the greater extraction of potassium ions [11]. Alcohol content in wines made with GMP was also significantly higher than that in control wine, which is likely due to the residual sugar remained in grape marc after pressing. There are significant differences in residual sugar in wines between treatment, but they were all lower than 4 g/L, which is considered as dry. Major differences in resultant wines were observed in total phenolics and tannins, with significantly higher level observed in Pinot noir wines made with GMP. This is simply because the fine particle size of grape skins in GMP greatly facilitate the greater extraction of phenolic compounds [12].

Table 1. Oenological parameters of Pinot noir wines.

	Control	GMP100	GMP50	GMP25
Wine pH	3.73 ± 0.01 a	3.93 ± 0.01 b	3.84 ± 0.01 c	3.74 ± 0.01 a
Alcohol content (%)	13.3 ± 1.2 a	16.9 ± 0.5 b	15.7 ± 1.0 c	15.3 ± 1.7 c
Residual sugar (g/L)	0.4 ± 0.3 a	2.8 ± 0.2 b	3.9 ± 0.2 c	1.5 ± 0.1 d
Total phenolics (mg/L)	1220 ± 2.1 a	3790 ± 0.7 b	2420 ± 7.3 c	1660 ± 5.1 d
Tannins (mg/L)	436 ± 48.3 a	2160 ± 53.9 b	1440 ± 49.5 c	684 ± 67.7 d

Different letters in the same row indicate statistically significant difference.

3.2 Colour parameters

Table 2 shows the color parameters in resultant Pinot noir wines. There was no significant difference in the degree of ionization of anthocyanins because of similar wine pH between treatments. Anthocyanins were significantly lower in Pinot noir wines made with GMP than in control wine, as grape skin is the only source of anthocyanins. Interestingly, GMP100 also showed significantly lower anthocyanins than control, although similar amount of grape skin was involved in both fermentations. This is likely due to the interaction of anthocyanins with tannins to form the polymerised pigments [1]. As a result, GMP100 and GMP50 showed significantly higher colour density, hue, and SO_2-resistant pigments than control. However, GMP25 showed significantly lower colour density and SO_2-resistant pigments than control, which is likely the result of limited anthocyanins extracted from reduced amount of GMP. Previous study has shown that the high ratio of anthocyanins and tannins is important to retain more tannins and form more polymeric pigments in wine [13].

Table 2. Color parameters of Pinot noir wines.

	Control	GMP100	GMP50	GMP25
Degree of ionization of ANC* (%)	0.14 ± 0.00 a	0.14 ± 0.01 a	0.12 ± 0.01 a	0.12 ± 0.00 a
Total ANC (mg/L)	266 ± 4.3 a	216 ± 17.3 b	138 ± 1.4 c	101 ± 1.9 d
Colour density (AU)	5.11 ± 0.12 a	11.80 ± 0.27 b	6.06 ± 0.17 c	3.63 ± 0.18 d
Colour density SO_2 corrected (AU)	5.57 ± 0.01 a	11.70 ± 0.11 b	5.99 ± 0.11 c	3.52 ± 0.12 d
Hue	0.71 ± 0.01 a	1.03 ± 0.03 b	1.02 ± 0.01 b	0.99 ± 0.01 b
SO_2-resistant pigments (AU)	1.12 ± 0.03 a	4.31 ± 0.15 b	2.18 ± 0.06 c	1.20 ± 0.02 a

*Anthocyanins, different letters in the same row indicate statistically significant difference.

3.3 Analysis of phenolic composition

Table 3 shows the monomeric phenolic composition of Pinot noir wines from the four treatments. In general, the concentrations of monomeric phenolics in resultant wines between treatments were in consistency with the results of total phenolic and tannins, with GMP treatments showing significantly higher levels than control. Flavan-3-ols are the most abundant monomeric phenolics in the resultant Pinot noir wines as expected [8]. The concentrations of malvidin-3-O-glucoside in resultant wines was also consistent with the results of

total anthocyanins measured by Somers assay. Other phenolic compounds observed with significantly higher level in GMP treatments include catechin, epicatechin, quercetin, gallic acid, protocatechuic acid, caftaric acid, and resveratrol.

Table 3. Phenolic composition of Pinot noir wines.

Phenolics	Control	GMP100	GMP50	GMP25
Flavan-3-ols				
Catechin	89.5 ± 3.0 a	478.4 ± 25.7 b	275.9 ± 13.4 c	167.9 ± 0.8 d
Epicatechin	32.7 ± 1.1 a	220.3 ± 11.8 b	128.7 ± 4.7 c	73.8 ± 6.1 d
Malvidin-3-O-glucoside	171.1 ± 4.4 a	117.1 ± 6.7 b	79.8 ± 0.4 c	59.9 ± 1.3 d
Flavonols				
Quercetin	0.5 ± 0.1 a	2.4 ± 0.2 b	1.3 ± 0.1 c	0.9 ± 0.1 c
Quercetin-3-glucoside	0.5 ± 0.1 a	1.2 ± 0.6 a	0.6 ± 0.0 a	ND
Benzoic acids				
Gallic acid	10.8 ± 0.5 a	56.5 ± 2.6 a	30.9 ± 1.3 c	17.5 ± 0.1 d
Syringic acid	2.7 ± 0.1 a	14.8 ± 0.9 b	1.9 ± 0.0 a	2.3 ± 1.1 a
Protocatechuic acid	1.0 ± 0.0 a	2.9 ± 0.2 b	2.2 ± 0.2 c	1.9 ± 0.0 c
Hydroxybenzoic acid	0.4 ± 0.0 ac	1.1 ± 0.1 b	0.5 ± 0.0 a	0.3 ± 0.0 c
Hydroxycinnamic acids				
Caftaric acid	4.5 ± 0.4 a	12.2 ± 0.7 b	14.7 ± 1.2 bc	16.3 ± 0.2 c
cis-Coutaric acid	ND	0.2 ± 0.2	ND	ND
trans-Coutaric acid	0.8 ± 0.0 a	ND	1.1 ± 1.0 a	1.6 ± 0.4 a
Caffeic acid	0.8 ± 0.4 a	1.2 ± 0.7 a	1.1 ± 0.2 a	1.1 ± 0.2 a
p-Coumaric acid	0.7 ± 0.6 a	1.2 ± 1.0 a	0.1 ± 0.0 a	0.3 ± 0.5 a
Ferulic acid	ND	0.5 ± 0.1 a	0.2 ± 0.0 b	0.1 ± 0.0 c
GRP	0.4 ± 0.1 a	0.5 ± 0.2 a	0.5 ± 0.1 a	0.6 ± 0.0 a
Stilbenes				
Resveratrol	0.1 ± 0.0 a	0.4 ± 0.0 b	0.3 ± 0.0 b	0.3 ± 0.0 b

Different letters in the same row indicate statistically significant difference.

3.4 Aroma profiling

There were 47 aroma compounds in total identified and quantified in resultant Pinot noir wines (Table 4), including esters, volatile fatty acids, higher alcohols, aldehydes, volatile phenols, norisoprenoids, and monoterpenes. Most of aroma compounds determined in resultant wines showed significant differences between treatments. In general, esters, responsible of fruity aromas in wine, are the most abundant aroma compounds observed in resultant wines, followed by volatile fatty acids and higher alcohols. Pinot noir wines made with addition of GMP tend to show significantly higher concentrations of acetate esters (except of 2-Methylbutyl acetate), 2-phenylethyl acetate, diethyl succinate, and ethyl decanoate. Concentration of volatile fatty acids varied between treatments, with some showing significantly higher levels in control (e.g. isobutyric acid and isovaleric acid) and others showing higher levels in GMP treatments (e.g. octanoic acid). It tends to show a lower level of higher alcohols in GMP treatments, especially 1-hexanol, 1-heptanol, and 1-octanol, which are associated with vegetative/green, fatty/oily, and floral aromas respectively. GMP treatments also showed significantly lower concentration of benzaldehyde that give almond-like aromas to the wine. There were significant differences in volatile phenols between treatments, with lower concentrations of guaiacol, 4-ethyl guaiacol, and eugenol observed in Pinot noir wines added with GMP. Norisoprenoids (β-damascenone and β-ionone) and monoterpenes (geraniol, linalool, nerol, and citronellol) were determined with significantly lower concentrations in GMP treatments, likely due to the limited extraction of precursors of these aroma compounds from grape skins [5].

Table 4. Quantification of aroma compounds by GC-MS.

Aroma compounds*	Control	GMP100	GMP50	GMP25
Acetate Esters				
Ethyl acetate§	64.3 ± 0.9b	127 ± 39a	95.1 ± 5.7ab	84.7 ± 3.7ab
Isobutyl acetate	55.0 ± 6.4c	184 ± 12b	223 ± 7a	214 ± 6a
2-Methylbutyl acetate	431 ± 40	ND	ND	ND
Isoamyl acetate§	0.33 ± 0.02c	1.71 ± 0.51b	2.21 ± 0.09ab	2.64 ± 0.07a
Hexyl acetate	13.6 ± 1.0d	48.6 ± 12.7c	73.5 ± 0.9b	110 ± 8a
Octyl acetate	6.09 ± 0.15c	8.86 ± 1.31bc	11.7 ± 0.9ab	14.2 ± 1.8a
Ethyl Esters				
Ethyl isobutyrate	38.1 ± 1.32a	27.3 ± 4.43b	26.5 ± 0.69b	26.3 ± 0.78b
Ethyl butyrate	247 ± 15a	370 ± 104a	366 ± 17a	385 ± 8a
Ethyl lactate§	1.14 ± 0.06b	2.04 ± 0.14a	1.20 ± 0.16b	1.04 ± 0.06b
Ethyl 2-methylbutyrate	6.32 ± 0.62a	2.84 ± 0.09b	2.60 ± 0.19b	2.41 ± 0.20b
Ethyl isovalerate	7.21 ± 0.36a	4.80 ± 0.96b	3.98 ± 0.11b	3.65 ± 0.05b
Ethyl pentanoate	1.50 ± 0.04ab	1.74 ± 0.39a	1.18 ± 0.06ab	1.12 ± 0.16b
Ethyl hexanoate§	0.68 ± 0.04b	0.98 ± 0.27ab	1.02 ± 0.04ab	1.11 ± 0.05a
Ethyl heptanoate	4.82 ± 0.20a	2.60 ± 0.60b	2.15 ± 0.03b	2.22 ± 0.22b
2-Phenylethyl acetate	43.1 ± 1.0d	98.0 ± 2.9c	203 ± 5b	311 ± 8a
Ethyl octanoate§	1.09 ± 0.13b	1.75 ± 0.61ab	1.78 ± 0.08ab	2.16 ± 0.32a
Diethyl succinate	299 ± 29b	661 ± 111a	435 ± 44b	273 ± 68b
Ethyl cinnamate	1.85 ± 0.36a	1.37 ± 0.11ab	1.08 ± 0.04b	0.89 ± 0.01b
Ethyl hydrocinnamate	115 ± 5b	137 ± 9a	123 ± 3ab	98.6 ± 3.9c
Ethyl decanoate§	0.48 ± 0.05b	1.15 ± 0.39a	1.24 ± 0.11a	1.59 ± 0.13a
Volatile fatty acids(FA)				
Acetic acid§	15.4 ± 0.9b	19.6 ± 1.6a	9.74 ± 0.76c	6.48 ± 0.43d
Butyric acid	128 ± 8a	115 ± 10a	123 ± 1a	123 ± 2a
Isobutyric acid	248 ± 12a	190 ± 17b	170 ± 2bc	152 ± 1c
2-methylbutyric acid	160 ± 5a	86.5 ± 3.0c	96.5 ± 1.1b	91.3 ± 1.8bc
Isovaleric acid	165 ± 5a	120 ± 4bc	123 ± 1b	114 ± 1c
Hexanoic acid	339 ± 23ab	242 ± 6c	321 ± 4b	367 ± 14a
Octanoic acid	183 ± 14c	148 ± 5d	239 ± 1b	307 ± 6a
Higher alcohols				
Isobutyl alcohol§	46.9 ± 3.2a	49.2 ± 8.1a	42.9 ± 3.2a	40.3 ± 2.2a
Isoamyl alcohol§	255 ± 14b	346 ± 66a	296 ± 17ab	279 ± 3ab
cis-3-Hexen-1-ol	40.2 ± 2.2a	35.2 ± 7.6ab	28.6 ± 2.4b	25.2 ± 2.8b
trans-3-Hexen-1-ol	23.1 ± 1.6a	19.2 ± 4.1ab	15.6 ± 0.6b	13.9 ± 0.5b
trans-2-Hexen-1-ol	10.6 ± 0.9a	5.27 ± 2.15b	4.15 ± 0.10b	4.20 ± 0.75b
1-Hexanol§	4.32 ± 0.30a	2.03 ± 0.44b	1.75 ± 0.04b	1.78 ± 0.06b
1-Heptanol	70.5 ± 4.0a	19.0 ± 3.9b	11.6 ± 0.1c	9.09 ± 0.41c
Phenylethyl alcohol§	65.1 ± 3.9a	75.0 ± 16.2a	69.0 ± 2.8a	64.9 ± 1.7a
1-Octanol	53.1 ± 0.4a	37.0 ± 1.8b	38.3 ± 2.1b	31.3 ± 6.4b
Aldehydes				
Benzaldehyde	51.4 ± 2.5a	25.1 ± 7.5b	22.8 ± 0.6b	26.5 ± 0.8b
Volatile phenols				
Phenol	5.72 ± 0.33a	5.66 ± 0.20a	5.68 ± 0.15a	5.58 ± 0.16a
Guaiacol	9.56 ± 0.48a	8.76 ± 0.28a	6.58 ± 0.31b	5.79 ± 0.09b
4-Ethyl guaiacol	0.51 ± 0.18a	0.18 ± 0.01b	0.17 ± 0.01b	0.20 ± 0.01b
Eugenol	6.75 ± 0.94a	3.27 ± 0.26c	4.40 ± 0.18bc	5.37 ± 0.14b
Norisoprenoids				
β-Damascenone	24.8 ± 0.2a	19.6 ± 0.6c	20.6 ± 1.0bc	22.1 ± 0.7b
α-Ionone	0.06 ± 0.00a	0.05 ± 0.00b	0.05 ± 0.00b	0.04 ± 0.00c
β-Ionone	1.96 ± 0.10ab	1.97 ± 0.08a	1.83 ± 0.22ab	1.60 ± 0.11b
Monoterpenes				
Geraniol	14.6 ± 1.0a	12.1 ± 1.0ab	11.3 ± 0.9bc	9.19 ± 1.05c
Linalool	81.5 ± 5.4a	55.2 ± 9.8b	53.7 ± 14.9b	52.7 ± 3.7b
Nerol	9.01 ± 0.57a	4.80 ± 0.77b	5.27 ± 0.87b	3.86 ± 0.48b
Citronellol	15.2 ± 1.0a	8.44 ± 0.58b	8.51 ± 1.46b	8.84 ± 1.04b

*Expressed as μg/L, §expressed as mg/L. Different letters in the same row indicate statistically significant difference.

Figure 2 shows the aroma profiles of resultant Pinot noir wines based on seven aroma categories using OAVs of 47 aroma compounds determined in this study. Pinot noir wines made with addition of GMP showed significantly more fruity characteristics, and less vegetative/green, spicy, and woody characteristics. The enhanced fruity characters and reduced vegetative/green characters could make a positive contribution to the quality of Pinot noir wines.

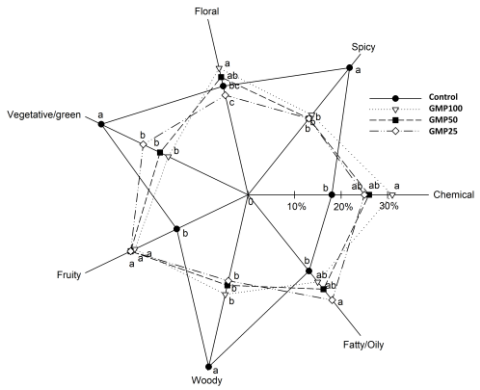

Figure 2. Characterisation of aroma active compounds in Pinot noir wines.

4 Conclusion

Pinot noir winemaking is challenging due to the limited colour and tannins available in grape skins compared to other red grape varieties. Pinot noir wines made with addition of grape marc powder showed significantly greater extraction of colour and tannins. Aroma profiling of resultant Pinot noir wines also suggested potential benefits of fermentation with grape marc powder via enhanced fruity characters and reduced vegetative/green characters. Grape marc is a major waste produced from winemaking and its disposal could be of a great environmental concern. This study provides information on an alternative way of upcycling grape marc to be reapplied in wine production, especially grape marc sourced from premium quality grapes. Future study could further investigate the use of 'premium' grape marc after pressing and consequent impact on sensory attributes, which might be feasible to improve the quality of wine made from less quality fruits.

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