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The Influence of Growing Region, Cultivar and Harvest Timing on the Diversity of Australian Olive Oil

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Abstract The quality indices and chemical composition of ten common olive cultivars grown in different regions of Australia were evaluated to determine the diversity of olive oils produced in Australia. Olives from trees from different environments including warmer climates in the north to colder climates in the south were sampled at two different stages of maturity over 2 years. The oil was extracted and standard methods were used to analyse the oil. Oleic acid content ranged from 83.4% in the Picual cultivar grown in Tasmania to 54.5% in Arbequina grown in northern New South Wales/southern Queensland. The Barnea cultivar, which is very commonly grown in Australia, was above 4% for campesterol content, regardless of the region in which it was grown. Parameters, such as palmitic acid, oleic acid, linoleic acid and wax content were found to be significantly affected by growing region for some cultivars. This study shows the growing conditions for olive in Australia gives rise to a diverse range of olive oils.

Keywords Olive oil · Campesterol · Cultivar · Fatty acid profile · Quality

Introduction

Olives have been grown in Australia since European settlement with the first olives reported to have been introduced as early as 1800 [1]. Despite that, the industry was slow to develop until the early 1990 s when olives became a burgeoning industry in Australia. There was a rapid increase from a negligible crop to an estimated production of 12,000 tonnes of oil in 2008. By 2010, the industry is expected to reach 25,000 tonnes [2] as orchards reach full maturity. There has been very little work done in Australia to determine the performance of olive cultivars in different regions of the continent.

While many researchers have shown that the cultivar can have a significant effect on fatty acid profile [3, 4], others [5] have shown that geographical location has a significant effect. This occurs due to different climactic conditions at each growing site, including rainfall, temperature and humidity. Furthermore, the percentage of unsaturated fatty acids in olive oil increases with decreasing temperature or increasing altitude [6].

Sterols are important components in human health and nutrition. Phytosterols found in vegetables and plant oils, such as β-sitosterol have been shown to reduce cholesterol absorption in humans resulting in reduced health problems [7]. The International Olive Council (IOC) imposes limits or ranges for each type of sterol based on the natural levels found in traditional olive oil types. Sterol profiles outside these ranges could suggest that the olive oil is not genuine. A number of cases have found olive oils which naturally exceed the limits for sterols. This is particularly so in the case of campesterol which is specified to be less than 4% of total sterols according to the standard limits. Cultivars in which the campesterol content has exceeded this limit include Arbequina, Corniche, Koroneiki, Cornicabra, Arauco and Barnea [8–13]. Erythrodiol levels are high in solvent extracted or refined oils (i.e. pomace oils) and therefore high levels in virgin oils would indicate adulteration with pomace oil [14].

Waxes are mostly present on the external fruit wax cuticle in olives [15]. The waxes on the surface of the fruit

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protects them against water loss and insect damage. In dry hot weather, plants are known to produce more waxes to control the rate of transpiration in order to reduce water loss [16]. Extra virgin olive oil is characterised by the virtual absence of waxes with 40–46 carbon atoms, as these compounds are not extracted by mechanical processing. The waxes are found in comparatively large amounts in refined and pomace oil as they are dissolved in the solvents used in the extraction process. Therefore, the presence of waxes is a good method for identifying solvent extracted oil (pomace oil) in virgin olive oil [17].

Tocopherols are well known for their inhibition of lipid oxidation in foods and biological systems. Vitamin E or α-tocopherol is only synthesized by plants and is an important dietary nutrient for human. The tocopherol content of food increases storage life by protecting food lipids from autoxidation. Oils have varying amounts of tocopherols present, therefore the analysis of this components can be an useful tool in the identification of adulteration of olive oil [18].

The aim of this work has been to examine the influence of growing regions on some of the components of olive oil produced in Australia. These regions have a wide range of climates, from tropical Queensland in the north, to much colder climates in southern regions including Tasmania. This study will contribute to the overall understanding of the characterization of Australian olive oils and their comparison with international quality criteria.

Experimental Procedures

Olive fruit samples from ten of the most common cultivars grown in Australia, Arbequina, Barnea, Coratina, Corregiolla, Frantoio, Koreneiki, Leccino, Manzanillo, Pendolino and Picual were evaluated. Samples were collected from the 2005 and 2006 growing seasons from sites in four different regions in Australia. These regions were: Northern New South Wales/Southern Queensland (29°S, 149°E); South-Western Western Australia (32°S, 116°E); Central Victoria (36°S, 143°E) and Tasmania (42°S, 147°E). These regions were selected to represent a range of extremes of conditions across olive growing areas within Australia.

Olive Oils

Olive fruit (2 kg) of each cultivar was harvested at two maturity dates at the four sites. Due to vast differences in olive fruit maturation rates at each site, the harvest dates were: NSW/Queensland—early April and mid May; Western Australia and Victoria—early May and early June; Tasmania—late May and late June. These harvest times are indicative of normal commercial harvesting periods in these regions. The fruit was harvested and packed into calico bags and placed into cold (12 °C) storage. The oil was extracted within 24 h.

Oil Extraction

Oils were extracted using a laboratory scale mechanical extraction unit (Abencor, Spain). It consists of a hammer mill, a thermo-malaxer and a centrifuge. Approximately 1 kg of fruit was ground to a paste using the hammer mill. The sample was thoroughly mixed and 700 g of the pulp was weighed into a mixing jar, placed in the thermo-malaxer and allowed to stir for 20 min at 25 °C. Boiling water (300 ml) was added, and the sample was stirred for a further 10 min. The sample was centrifuged (3,500 rpm) for 1 min. The oily must (i.e. the mixture of oil, water and vegetable solid) was collected in a measuring cylinder; the pomace was rinsed with 100 ml of boiling water, centrifuged (3,500 rpm) for 1 min, and the must again collected. After allowing 1 h for the sample to settle, the oil was transferred to a glass bottle and sealed under nitrogen until analysis.

Analytical Methods

Fatty acid methyl esters were prepared by trans-esterification with cold methanolic potassium hydroxide (Lomb Scientific, Australia) using the official method of the International Olive Council, COI/T.20/Doc. No 24 [19]. The fatty acid profiles were determined by gas chromatography using a SGE BPX70 (Alltech, Australia) capillary column (30 m, 0.25 mm, 0.25 μm film) and a flame ionization detector (FID). The column temperature program was: 185 °C for 8 min; increased at 10 °C/min to a final temperature of 220 °C, held for 3 min; injector temperature 250 °C; detector temperature 260 °C.

Sterols and erythrodiols were determined according to the official method of the International Olive Council, COI/T.20/Doc. No 10 [20]. Internal standard, α-cholestanol and betulinol (Sigma–Aldrich, Australia), was added to the sample which was then saponified using 2N potassium hydroxide (Lomb Scientific, Australia). The unsaponifiable fraction was removed with diethyl ether, and the sterols were further separated using TLC. Silica gel 60 Thin layer chromatography plates were used (20 cm × 20 cm) (Merck, Australia), and the mobile phase was toluene:acetone (95:5, v/v) (Lomb, Australia). The sterols and diols were determined by gas chromatography using a J and W Scientific SE-54 (Alltech, Australia) capillary column (30 m, 0.25 mm, 0.25 μm) and an FID. The column temperature program was 265 °C for 45 min, increased at 5 °C/min, final temperature 300 °C; held for

5 min; injector temperature 280 °C; detector temperature 290 °C.

The wax fraction was separated from the oil using a hydrated silica gel (Sigma–Aldrich, Australia), column, according to the official method, COI/T.20/Doc. No 18 [21]. The waxes were determined by gas chromatography using an SGE BPX5 (Alltech, Australia) capillary column (12 m, 0.53 mm, 0.25 μm) and an FID. The column temperature program was as follows: Initial temperature 80 °C, increasing to 120 °C at 30 °C/min, hold for 1 min, then increasing to 340 °C at 5 °C/min, hold for 17 min; injector temperature 230 °C; detector temperature 350 °C.

α-Tocopherol was measured using IUPAC method 2-432 [22]. Separation of tocopherol was completed on a Luna 5u Silica column (250 × 4.6 mm; Phenomonex, Australia) using a mobile phase of hexane:isopropanol (99:1). A flow rate of 1 ml/min and detection at 292 nm were used during the separation.

Data were analysed using GenStat version 9.1 (Lawes Agricultural Trust, UK). Analysis of Variance (ANOVA) was used to determine differences among means.

Results and Discussion

Australia is a vast continent, and the growing regions used in this study were chosen because of the significantly different climates. Northern New South Wales and Southern Queensland (NSW/Qld) generally have higher maximum and minimum temperatures than the southern growing areas. The Western Australian (WA) and Victorian (Vic) sites, were at a more southerly latitude and the climate was generally milder. The most southern of the sites, Tasmania (Tas) had a much cooler climate than the other sites. Generally, the components analyzed in this study were not affected by growing season or time of harvest, therefore the results tables (Tables 1, 2, 3) show only the mean of the cultivar for that component at that site.

Fatty Acid Profile

Palmitic acid (C16:0) was affected by growing region ($p < 0.05$) for all cultivars except Koreneiki and Manzanillo. In most cases, palmitic acid was higher in the northern, hotter climates. Tasmania, with the coolest climate, always had the lowest palmitic acid value for each cultivar. Arbequina from Northern NSW/Qld had the highest mean (19.7%), while Barnea from Tasmania was the lowest (8.0%) (Table 1).

All cultivars were significantly affected by growing region for palmitoleic acid content (C16:1) ($p < 0.01$). As with the palmitic acid, cultivars grown in the southern region always had lower levels than those grown further north. Arbequina grown in NSW/Qld, with a mean of 3.5% palmitoleic acid, had the highest concentration while Coratina from Tasmania was the lowest (0.3%) (Table 1).

The mean for stearic acid (C18:0) ranged from 3.4% in Manzanillo in NSW/Qld, to 1.1% for Pendolino in WA (Table 1). Only the Arbequina, Barnea, Frantoio, Manzanillo and Pendolino cultivars were influenced by growing region ($p < 0.05$). Leccino was affected by growing season ($p < 0.05$), with a mean for 2005 and 2006 of 1.6 and 1.9%, respectively.

Arbequina cultivar grown in NSW/Qld had the lowest oleic acid (C18:1) content with a mean of 54.5% (Table 1) while Picual grown in Tasmania had the highest with 83.4%. All cultivars were significantly affected by region ($p < 0.01$), however, they were not affected by season or harvest time. In every case the oleic acid content was lowest in the northern hotter regions, increasing in the regions further south with cooler climates.

Linoleic acid (C18:2) was not significantly affected by season or harvest time, however, region did have a significant effect ($p < 0.05$). The highest mean content was 19.4% in the Arbequina from NSW/Queensland, and the minimum was 2.6% in the Picual from Tasmania (Table 1). In nearly all cases, the linoleic acid content for each cultivar was highest in the northern region of NSW/Queensland, and decreased further south in the cooler climates.

Manzanillo and Picual were found to be significantly affected by region ($p < 0.05$) for linolenic acid (C18:3), however, the other cultivars were not affected. There was a season effect ($p < 0.05$) for Coratina between 2005 and 2006 (0.7 and 0.8%, respectively), although there were no other year or harvest effects.

Similar research on other oil crops such as sunflower, canola and safflower have found that geographical location has an influence on the development of fatty acids [23]. This is due to a number of factors such as soil type, agronomic conditions and climate. Climate in particular can have an influence on fatty acid composition, as temperatures at certain periods during maturation in canola, soybean and sunflower have been shown to have a significant effect [24].

Sterols and Erythrodiols

For all cultivars and at all sites the brassicasterol content was found to be less than <0.1% of the total sterols. Brassicasterol is an important indicator of contamination of olive oil with *Brassica* oils and the lack of that component in this study verifies its value in testing for adulteration of genuine olive oil. The cholesterol content was low, with a maximum of 0.3% of total sterols.

Campesterol content was found to be higher than 4% in Barnea in all growing regions, which is above the

Table 1 Mean value and standard deviation of fatty acids from ten cultivars grown in four different regions in Australia

Cultivar	Region[a]	% Of total fatty acids[b]					
		C16:0	C16:1	C18:0	C18:1	C18:2	C18:3
Arbequina	NSW/Qld	19.7 ± 0.5[a]	3.5 ± 0.4[a]	1.2 ± 0.2[a]	54.5 ± 1.9[a]	19.4 ± 1.1[a]	0.7 ± 0.1[a]
	WA	16.4 ± 1.4[a,b]	2.1 ± 0.3[b]	1.5 ± 0.1[a]	63.4 ± 3.4[a,b]	14.3 ± 1.5[b]	0.6 ± 0.1[a]
	Vic	14.8 ± 2.3[b]	1.8 ± 0.6[b,c]	1.5 ± 0.2[a]	69.7 ± 5.8[b]	10.6 ± 3.3[b]	0.6 ± 0.0[a]
	Tas	10.4 ± 1.4[c]	0.8 ± 0.3[c]	1.9 ± 0.4[a]	81.0 ± 4.3[c]	4.4 ± 1.5[c]	0.6 ± 0.1[a]
Barnea	NSW/Qld	14.5 ± 0.4[a]	1.2 ± 0.1[a]	1.8 ± 0.1[a]	63.0 ± 4.0[a]	18.1 ± 4.0[a]	0.7 ± 0.1[a]
	WA	11.7 ± 1.4[b]	0.8 ± 0.2[b]	2.0 ± 0.2[a,b]	70.8 ± 1.1[b]	13.2 ± 1.0[a,b]	0.6 ± 0.1[a]
	Vic	11.4 ± 1.8[b]	0.9 ± 0.2[b]	1.8 ± 0.2[a]	73.2 ± 3.5[b,c]	11.3 ± 2.1[b]	0.6 ± 0.0[a]
	Tas	8.0 ± 0.7[c]	0.5 ± 0.1[b]	2.3 ± 0.2[b]	79.6 ± 2.2[c]	8.1 ± 0.6[b]	0.6 ± 0.0[a]
Coratina	NSW/Qld	12.3 ± 2.0[a]	0.5 ± 0.1[a]	2.0 ± 0.3[a]	74.0 ± 2.4[a]	9.5 ± 0.9[a]	0.8 ± 0.1[a]
	WA	12.4 ± 1.7[a]	0.4 ± 0.0[a,b]	1.8 ± 0.3[a]	76.3 ± 2.1[a,b]	7.2 ± 0.8[b]	0.8 ± 0.1[a]
	Vic	11.0 ± 1.4[a]	0.4 ± 0.1[a,b]	1.6 ± 0.2[a]	78.0 ± 1.5[b]	7.3 ± 1.1[b]	0.7 ± 0.1[a]
	Tas	8.5 ± 0.7[a]	0.3 ± 0.0[b]	1.7 ± 0.3[a]	81.8 ± 0.4[c]	6.1 ± 1.0[b]	0.7 ± 0.1[a]
Corregiola	NSW/Qld	15.3 ± 0.9[a]	1.3 ± 0.2[a]	1.7 ± 0.2[a]	68.9 ± 3.7[a]	11.2 ± 2.9[a]	0.7 ± 0.1[a]
	WA	13.5 ± 1.8[a]	1.1 ± 0.2[a]	1.8 ± 0.3[a]	71.6 ± 3.2[a]	10.5 ± 1.6[a]	0.6 ± 0.1[a]
	Vic	–	–	–	–	–	–
	Tas	8.7 ± 1.4[b]	0.5 ± 0.2[b]	1.9 ± 0.1[a]	80.5 ± 2.1[b]	6.9 ± 0.5[b]	0.5 ± 0.1[a]
Frantoio	NSW/Qld	15.6 ± 0.5[a]	1.7 ± 0.2[a]	1.6 ± 0.3[a,b]	65.7 ± 3.8[a]	13.8 ± 2.9[a]	0.7 ± 0.1[a]
	WA	13.8 ± 1.8[a,b]	1.1 ± 0.2[b]	1.7 ± 0.1[a,b]	70.3 ± 4.0[a]	11.6 ± 2.5[a]	0.6 ± 0.1[a]
	Vic	12.9 ± 1.8[b]	1.0 ± 0.2[b]	1.5 ± 0.2[a]	72.0 ± 3.5[a]	11.1 ± 1.8[a]	0.6 ± 0.1[a]
	Tas	9.1 ± 1.2[c]	0.4 ± 0.1[c]	2.0 ± 0.3[b]	80.3 ± 1.2[b]	6.7 ± 0.5[b]	0.6 ± 0.2[a]
Koreneiki	NSW/Qld	13.8 ± 0.6[a]	1.1 ± 0.0[a]	2.0 ± 0.1[a]	75.4 ± 0.6[a]	6.1 ± 0.3[a]	0.7 ± 0.1[a]
	WA	10.7 ± 1.5[a]	0.8 ± 0.1[b]	2.4 ± 0.3[a]	76.6 ± 0.5[b]	8.0 ± 1.4[b]	0.5 ± 0.0[a]
	Vic	11.1 ± 0.6[a]	0.8 ± 0.1[b]	2.3 ± 0.1[a]	79.8 ± 0.3[c]	4.5 ± 0.3[c]	0.5 ± 0.1[a]
	Tas	–	–	–	–	–	–
Leccino	NSW/Qld	14.7 ± 0.5[a]	1.4 ± 0.2[a]	1.6 ± 0.1[a]	73.1 ± 0.9[a]	7.9 ± 1.1[a]	0.6 ± 0.1[a]
	WA	13.1 ± 1.1[a,b]	1.1 ± 0.0[a,b]	1.8 ± 0.4[a]	75.4 ± 0.2[b]	7.3 ± 0.7[a]	0.6 ± 0.1[a]
	Vic	13.2 ± 1.5[a,b]	1.1 ± 0.2[a,b]	1.7 ± 0.4[a]	77.1 ± 1.2[c]	5.5 ± 0.7[b]	0.6 ± 0.0[a]
	Tas	11.6 ± 1.2[b]	0.8 ± 0.3[b]	1.9 ± 0.4[a]	77.9 ± 0.5[c]	6.4 ± 0.7[a,b]	0.6 ± 0.1[a]
Manzanillo	NSW/Qld	15.4 ± 0.9[a]	1.8 ± 0.2[a]	3.4 ± 0.4[a]	63.6 ± 1.7[a]	13.8 ± 1.4[a]	0.8 ± 0.1[a]
	WA	12.9 ± 1.4[a]	1.2 ± 0.1[b]	3.0 ± 0.4[a]	72.4 ± 1.2[b]	8.7 ± 1.8[b]	0.6 ± 0.1[b]
	Vic	12.5 ± 1.1[a]	1.4 ± 0.2[b]	2.9 ± 0.4[a]	75.0 ± 1.5[c]	6.5 ± 1.9[b]	0.6 ± 0.1[a,b]
	Tas	–	–	–	–	–	–
Pendolino	NSW/Qld	–	–	–	–	–	–
	WA	12.8 ± 1.1[a]	0.8 ± 0.1[a]	1.1 ± 0.1[a]	74.5 ± 1.9[a]	9.1 ± 0.7[a]	0.8 ± 0.2[a]
	Vic	12.2 ± 0.5[a]	0.7 ± 0.1[b]	1.2 ± 0.0[a]	77.1 ± 0.3[a,b]	7.1 ± 0.3[b]	0.9 ± 0.1[a]
	Tas	9.7 ± 0.2[b]	0.4 ± 0.0[c]	1.5 ± 0.0[b]	79.4 ± 1.0[b]	7.3 ± 1.3[a,b]	0.8 ± 0.1[a]
Picual	NSW/Qld	15.3 ± 1.1[a]	2.2 ± 0.5[a]	1.8 ± 0.2[a]	72.6 ± 3.2[a]	6.4 ± 2.0[a]	0.9 ± 0.2[a]
	WA	11.7 ± 1.7[b]	1.0 ± 0.3[b]	2.5 ± 0.7[a]	78.7 ± 1.5[b]	4.6 ± 0.8[a,b]	0.7 ± 0.1[a,b]
	Vic	11.8 ± 1.7[b]	1.0 ± 0.2[b]	2.3 ± 0.7[a]	80.4 ± 1.0[b]	3.1 ± 0.9[b]	0.6 ± 0.0[b]
	Tas	9.6 ± 1.4[b]	0.6 ± 0.2[b]	2.4 ± 0.5[a]	83.4 ± 0.8[c]	2.6 ± 0.3[b]	0.6 ± 0.0[b]

–, Samples were not collected from those sites

[a] *NSW/Qld* New South Wales and Queensland, *WA* Western Australia, *Vic* Victoria, *Tas* Tasmania

[b] Values within a single column (within each cultivar) with a different letter indicates that they are significantly different ($p < 0.05$)

maximum allowable levels in international standards (Table 2). Koreneiki was also found to exceed 4% in NSW/Qld and Victoria. The campesterol content was found to be affected by growing region for Barnea, Arbequina, Koreneiki, Leccino and Pendolino cultivars ($p < 0.05$), which in most cases show a trend of higher campesterol content in

Table 2 Mean value and standard deviation of sterols and diols grown in four different regions in Australia

Cultivar	Region[a]	% Of total sterols[b]							
		Cholesterol	Brassicasterol	Campesterol	Stigmasterol	D-7- Stigmastenol	Apparent β-sitosterol	Diols	Total sterols (mg/kg)
Arbequina	NSW/Qld	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	3.3 ± 0.1^{a}	0.8 ± 0.1^{a}	0.2 ± 0.2^{a}	94.6 ± 0.3^{a}	1.2 ± 0.2^{a}	2140 ± 171^{a}
	WA	0.1 ± 0.0^{a}	0.0 ± 0.0^{a}	$3.6 \pm 0.1^{a,b}$	0.9 ± 0.1^{a}	0.2 ± 0.2^{a}	93.8 ± 1.2^{a}	1.0 ± 0.1^{a}	$1719 \pm 340^{a,b}$
	Vic	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	3.8 ± 0.2^{b}	1.0 ± 0.1^{a}	0.2 ± 0.1^{a}	93.9 ± 0.6^{a}	1.6 ± 0.2^{a}	1570 ± 294^{b}
	Tas	0.2 ± 0.1^{a}	0.0 ± 0.0^{a}	$3.3 \pm 0.5^{a,b}$	0.4 ± 0.2^{b}	0.2 ± 0.1^{a}	94.5 ± 0.4^{a}	1.8 ± 0.4^{a}	1381 ± 62^{b}
Barnea	NSW/Qld	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	4.3 ± 0.2^{a}	0.7 ± 0.2^{a}	0.2 ± 0.1^{a}	93.6 ± 0.8^{a}	1.2 ± 0.2^{a}	1762 ± 152^{a}
	WA	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	4.1 ± 0.2^{a}	$0.7 \pm 0.2^{a,b}$	0.2 ± 0.1^{a}	93.8 ± 0.8^{a}	0.6 ± 0.2^{a}	1681 ± 139^{a}
	Vic	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	4.6 ± 0.1^{b}	0.4 ± 0.1^{b}	0.1 ± 0.1^{a}	93.6 ± 0.7^{a}	1.0 ± 0.5^{a}	1686 ± 257^{a}
	Tas	0.1 ± 0.0^{a}	0.0 ± 0.0^{a}	4.8 ± 0.2^{b}	0.1 ± 0.1^{c}	0.1 ± 0.1^{a}	94.0 ± 0.2^{a}	1.2 ± 0.8^{a}	1576 ± 195^{a}
Coratina	NSW/Qld	0.3 ± 0.1^{a}	0.0 ± 0.0^{a}	3.0 ± 0.2^{a}	0.7 ± 0.3^{a}	0.3 ± 0.1^{a}	94.8 ± 0.5^{a}	1.9 ± 0.2^{a}	1452 ± 450^{a}
	WA	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	3.1 ± 0.1^{a}	0.6 ± 0.1^{a}	0.2 ± 0.1^{a}	94.7 ± 1.1^{a}	1.7 ± 0.4^{a}	1296 ± 153^{a}
	Vic	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	3.3 ± 0.2^{a}	0.7 ± 0.1^{a}	0.1 ± 0.1^{a}	94.8 ± 0.5^{a}	1.4 ± 0.6^{a}	1235 ± 95^{a}
	Tas	0.2 ± 0.1^{a}	0.0 ± 0.0^{a}	3.3 ± 0.2^{a}	0.4 ± 0.1^{a}	0.2 ± 0.1^{a}	94.7 ± 0.5^{a}	1.4 ± 0.8^{a}	1190 ± 106^{a}
Corregiola	NSW/Qld	0.1 ± 0.0^{a}	0.0 ± 0.0^{a}	3.1 ± 0.2^{a}	0.5 ± 0.1^{a}	0.4 ± 0.1^{a}	94.8 ± 0.6^{a}	1.2 ± 0.5^{a}	1812 ± 244^{a}
	WA	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	2.8 ± 0.2^{a}	0.6 ± 0.1^{a}	0.3 ± 0.2^{a}	94.6 ± 1.4^{a}	0.8 ± 0.1^{a}	$1440 \pm 161^{a,b}$
	Vic	–	–	–	–	–	–	–	–
	Tas	0.2 ± 0.1^{a}	0.0 ± 0.0^{a}	2.9 ± 0.1^{a}	0.4 ± 0.1^{a}	0.2 ± 0.1^{a}	94.8 ± 0.3^{a}a	1.5 ± 0.4^{a}	1159 ± 177^{b}
Frantoio	NSW/Qld	0.1 ± 0.0^{a}	0.0 ± 0.0^{a}	2.9 ± 0.2^{a}	$0.7 \pm 0.0^{a,b}$	0.6 ± 0.4^{a}	94.7 ± 0.5^{a}	0.8 ± 0.3^{a}	1632 ± 154^{a}
	WA	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	2.9 ± 0.3^{a}	0.8 ± 0.2^{a}	0.3 ± 0.1^{b}	94.6 ± 0.4^{a}	0.9 ± 0.2^{a}	1568 ± 102^{a}
	Vic	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	3.1 ± 0.2^{a}	$0.6 \pm 0.2^{a,b}$	0.2 ± 0.1^{b}	94.8 ± 0.5^{a}	1.1 ± 0.4^{a}	1519 ± 191^{a}
	Tas	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	3.4 ± 0.4^{a}	0.5 ± 0.1^{b}	0.3 ± 0.2^{b}	94.2 ± 0.6^{a}	2.0 ± 1.0^{a}	1200 ± 88^{b}
Koreneiki	NSW/Qld	0.3 ± 0.2^{a}	0.0 ± 0.0^{a}	4.1 ± 0.3^{a}	0.9 ± 0.3^{a}	0.2 ± 0.1^{a}	93.3 ± 0.4^{a}	2.7 ± 0.0^{a}	$922 \pm 74^{a,b}$
	WA	0.3 ± 0.1^{a}	0.0 ± 0.0^{a}	3.2 ± 0.2^{b}	0.5 ± 0.2^{a}	0.2 ± 0.2^{a}	94.0 ± 0.2^{a}	2.8 ± 0.6^{a}	1267 ± 147^{a}
	Vic	0.2 ± 0.1^{a}	0.0 ± 0.0^{a}	4.6 ± 0.0^{c}	0.5 ± 0.1^{a}	0.3 ± 0.3^{a}	92.8 ± 0.6^{a}	4.0 ± 1.1^{a}	798 ± 12^{b}
	Tas	–	–	–	–	–	–	–	–
Leccino	NSW/Qld	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	$2.4 \pm 0.4^{a,b}$	1.1 ± 0.1^{a}	0.3 ± 0.1^{a}	94.5 ± 1.0^{a}	0.7 ± 0.3^{a}	1715 ± 277^{a}
	WA	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	2.2 ± 0.2^{a}	1.1 ± 0.3^{a}	0.3 ± 0.1^{a}	94.2 ± 0.9^{a}	0.8 ± 0.4^{a}	1579 ± 148^{a}
	Vic	0.1 ± 0.0^{a}	0.0 ± 0.0^{a}	2.9 ± 0.3^{b}	0.9 ± 0.1^{a}	0.2 ± 0.0^{b}	94.8 ± 0.2^{a}	1.2 ± 0.3^{a}	1371 ± 209^{a}
	Tas	0.1 ± 0.0^{a}	0.0 ± 0.0^{a}	2.8 ± 0.2^{b}	0.6 ± 0.1^{b}	0.2 ± 0.1^{b}	94.7 ± 0.5^{a}	1.2 ± 0.6^{a}	1448 ± 68^{a}
Manzanillo	NSW/Qld	0.1 ± 0.0^{a}	0.0 ± 0.0^{a}	2.7 ± 0.2^{a}	1.6 ± 0.3^{a}	0.2 ± 0.1^{a}	94.3 ± 0.7^{a}	1.7 ± 0.5^{a}	1803 ± 145^{a}
	WA	0.2 ± 0.1^{a}	0.0 ± 0.0^{a}	2.4 ± 0.2^{a}	1.1 ± 0.3^{a}	0.3 ± 0.1^{a}	94.7 ± 0.9^{a}	2.1 ± 0.9^{a}	1532 ± 193^{a}
	Vic	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	2.6 ± 0.1^{a}	1.0 ± 0.4^{a}	0.1 ± 0.1^{a}	95.2 ± 0.6^{a}	1.3 ± 0.2^{a}	1483 ± 171^{a}
	Tas	–	–	–	–	–	–	–	–
Pendolino	NSW/Qld	–	–	–	–	–	–	–	–
	WA	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	2.2 ± 0.1^{a}	0.6 ± 0.1^{a}	0.2 ± 0.1^{a}	95.3 ± 1.0^{a}	0.8 ± 0.3^{a}	1183 ± 122^{a}
	Vic	0.1 ± 0.0^{a}	0.0 ± 0.0^{a}	3.1 ± 0.1^{b}	0.5 ± 0.0^{a}	0.1 ± 0.1^{a}	95.0 ± 0.4^{a}	1.0 ± 0.1^{a}	944 ± 87^{a}
	Tas	0.1 ± 0.0^{a}	0.0 ± 0.0^{a}	3.0 ± 0.3^{b}	0.4 ± 0.1^{a}	0.2 ± 0.1^{a}	95.0 ± 0.7^{a}	0.9 ± 0.3^{a}	1063 ± 154^{a}
Picual	NSW/Qld	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	3.0 ± 0.5^{a}	0.8 ± 0.0^{a}	0.3 ± 0.2^{a}	94.3 ± 1.6^{a}	0.4 ± 0.3^{a}	1937 ± 498^{a}
	WA	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	3.4 ± 0.4^{a}	$0.7 \pm 0.3^{a,b}$	0.3 ± 0.2^{a}	94.5 ± 0.6^{a}	$0.9 \pm 0.3^{a,b}$	$1375 \pm 152^{a,b}$
	Vic	0.1 ± 0.1^{a}	0.0 ± 0.0^{a}	3.4 ± 0.3^{a}	$0.5 \pm 0.1^{a,b}$	0.3 ± 0.1^{a}	94.5 ± 0.6^{aq}	1.2 ± 0.3^{b}	1281 ± 229^{b}
	Tas	0.2 ± 0.0^{a}	0.0 ± 0.0^{a}	3.4 ± 0.3^{a}	0.3 ± 0.2^{b}	0.2 ± 0.1^{a}	94.4 ± 1.2^{a}	1.4 ± 0.3^{b}	$1458 \pm 64^{a,b}$

–, Samples were not collected from those sites

[a] *NSW/Qld* New South Wales and Queensland, *WA* Western Australia, *Vic* Victoria, *Tas* Tasmania

[b] Values within a single column (within each cultivar) with a different letter indicates that they are significantly different ($p < 0.05$)

the southern regions than in the north. There was a growing season effect in Coratina ($p < 0.05$) for campesterol content, averaging 3.0% in 2005 and 3.3% in 2006. It was shown that there was a significant harvest timing effect for the Picual cultivar ($p < 0.05$), with the early harvest at 3.2%, while the late harvest was 3.6%. All other cultivars were unaffected by growing season and harvest time.

Table 3 Mean value and standard deviation of waxes, UV absorption and α-tocopherol in four different regions in Australia

Cultivar	Region[a]	Waxes (mg/kg of oil)[b]	Spec. Ext. 270 nm ($K^{1\%}_{1\ cm}$)[b]	α-tocopherol (mg/kg of oil)[b]
Arbequina	NSW/Qld	179 ± 37[a]	0.14 ± 0.03[a]	253 ± 32[a]
	WA	153 ± 70[a,b]	0.09 ± 0.02[a]	213 ± 49[a]
	Vic	116 ± 25[a,b]	0.08 ± 0.01[a]	315 ± 42[a]
	Tas	55 ± 36[b]	0.15 ± 0.06[a]	286 ± 55[a]
Barnea	NSW/Qld	138 ± 26[a]	0.11 ± 0.00[a]	254 ± 41[a]
	WA	111 ± 19[a,b]	0.08 ± 0.01[a]	244 ± 17[a]
	Vic	78 ± 20[b]	0.08 ± 0.02[a]	290 ± 41[a]
	Tas	69 ± 4[b]	0.13 ± 0.02[b]	293 ± 50[a]
Coratina	NSW/Qld	39 ± 8[a]	0.15 ± 0.03[a]	481 ± 48[a]
	WA	22 ± 6[a]	0.15 ± 0.02[a]	352 ± 44[b]
	Vic	21 ± 10[a]	0.09 ± 0.04[a]	306 ± 34[b,c]
	Tas	27 ± 10[a]	0.16 ± 0.06[a]	244 ± 32[c]
Corregiola	NSW/Qld	146 ± 41[a]	0.08 ± 0.02[a]	287 ± 39[a]
	WA	87 ± 5[b]	0.10 ± 0.04[a]	162 ± 18[b]
	Vic	–	–	–
	Tas	40 ± 11[c]	0.13 ± 0.04[a]	159 ± 53[b]
Frantoio	NSW/Qld	122 ± 20[a]	0.10 ± 0.03[a]	251 ± 22[a]
	WA	113 ± 65[a]	0.09 ± 0.01[a]	180 ± 15[a]
	Vic	77 ± 27[a,b]	0.09 ± 0.02[a]	210 ± 46[a]
	Tas	40 ± 9[b]	0.14 ± 0.04[a]	178 ± 59[a]
Koreneiki	NSW/Qld	69 ± 1[a]	0.10 ± 0.00[a]	204 ± 11[a]
	WA	68 ± 12[a]	0.11 ± 0.04[a]	216 ± 15[a]
	Vic	41 ± 3[b]	0.18 ± 0.03[a]	251 ± 42[a]
	Tas	–	–	–
Leccino	NSW/Qld	77 ± 13[a]	0.07 ± 0.02[a]	462 ± 69[a]
	WA	54 ± 12[a]	0.06 ± 0.02[a]	394 ± 36[a]
	Vic	91 ± 68[a]	0.06 ± 0.02[a]	389 ± 51[a]
	Tas	41 ± 8[a]	0.12 ± 0.03[b]	374 ± 31[a]
Manzanillo	NSW/Qld	196 ± 62[a]	0.10 ± 0.02[a]	105 ± 57[a]
	WA	91 ± 36[b]	0.06 ± 0.02[b]	69 ± 8[a]
	Vic	54 ± 9[b]	0.08 ± 0.01[a,b]	152 ± 83[a]
	Tas	–	–	–
Pendolino	NSW/Qld	–	–	–
	WA	86 ± 44[a]	0.09 ± 0.05[a]	262 ± 40[a]
	Vic	73 ± 28[a]	0.08 ± 0.02[a]	362 ± 34[a]
	Tas	36 ± 9[a]	0.12 ± 0.05[a]	329 ± 67[a]
Picual	NSW/Qld	130 ± 46[a]	0.08 ± 0.02[a]	325 ± 59[a]
	WA	68 ± 25[a,b]	0.05 ± 0.01[a]	233 ± 38[a]
	Vic	41 ± 8[b]	0.08 ± 0.04[a]	263 ± 33[a]
	Tas	41 ± 6[b]	0.11 ± 0.04[a]	267 ± 29[a]

–, Samples were not collected from those sites

[a] *NSW/Qld* New South Wales and Queensland, *WA* Western Australia, *Vic* Victoria, *Tas* Tasmania

[b] Values within a single column (within each cultivar) with a different letter indicates that they are significantly different ($p < 0.05$)

The mean results for stigmasterol content ranged from 0.1% for Barnea grown in Tasmania, to 1.6% for Manzanillo grown in NSW/Qld (Table 2). There was a significant growing region effect for Arbequina, Barnea, Frantoio, Leccino, Pendolino and Picual ($p < 0.05$), however, none of the cultivars were affected by growing season or harvest time. Generally, the stigmasterol content was higher in the northern growing regions, and lower in the regions further to the south.

The Δ-7-stigmastenol content was found to be highest from the NSW/Qld growing region (0.6%) (Table 2). All other cultivars in all other regions were generally lower. Growing region had a significant effect on the Δ-7-stigmasterol content of the, Frantoio and Leccino cultivars ($p < 0.05$), and Arbequina had a significant harvest time effect ($p < 0.05$), (0.1% early harvest and 0.3% late harvest).

The apparent β-sitosterol content was unaffected by growing region and seasonal influences, and only Picual was affected by harvest time (Early harvest 94.9%; late harvest 93.9%, $p < 0.05$). The mean value for Koreneiki grown in Victoria was 92.8% (Table 2).

The total sterol content of olive oil usually varies between 1,000 and 2,000 mg/kg. Refined oils contain lower levels of total sterols because the refining process gives rise to significant loss of sterols (up to 25%). The total sterol content of solvent extracted oil, however, can be up to three times that of virgin olive oils [25].

The mean total sterol content for the 10 cultivars in this study ranged from 798 to 2,140 mg/kg (Table 2), with three samples, Koreneiki in NSW/Queensland and Victoria and Pendolino in Victoria, falling below 1,000 mg/kg. Arbequina, Corregiolla, Frantoio, Koreneiki, and Picual were all significantly affected by growing region ($p < 0.05$), with the total sterol content generally higher in northern regions and lowest in the most southern regions.

Erythrodiol levels are high in solvent extracted or refined oils (i.e. pomace oils) and therefore high levels in virgin oils would indicate adulteration with pomace oil [14].

The mean diols content from this study ranged from 0.4 to 4.0% (Table 2). Frantoio was affected by growing region ($p < 0.05$). Koreneiki had a harvest time effect ($p < 0.05$), with early harvest at 3.9 and 2.8% for the late harvest. Manzanillo was affected by growing season ($p < 0.05$), with the average results being 2.2% in 2005 and 1.4% in 2006.

Generally, sterol profiles and concentration have been shown not to be influenced by geographical location in other crops such as canola [26]. This study shows that generally, while geographical location can have an effect on the sterols in olive oil, the type of cultivar can also have an effect.

Waxes, UV Absorption and α-Tocopherol

Total wax content in this study was significantly affected ($p < 0.05$) by growing region for all cultivars except Koreneiki, Leccino and Pendolino. Generally, the wax content for each cultivar was higher in the northern climates (NSW/Qld) (Table 3), than those in the south (Tas). Coratina had a low wax content regardless of growing region. Manzanillo had the highest mean value for total wax content with 196 mg/kg oil, while the lowest mean value was 21 mg/kg in the Coratina cultivar grown in Victoria.

Coratina, Koreneiki, and Pendolino were not affected by growing region for ΔK, while all other cultivars were affected ($p < 0.05$). However, they were unaffected by harvest time or growing season. All results were below the International Olive Council limit (≤0.01) (data not shown). Specific extinction at 270 nm (K_{270}) was affected by growing region for the Barnea, Leccino and Manzanillo cultivars ($p < 0.05$). Koreneiki and Pendolino cultivars showed differences with harvest time ($p < 0.05$). Koreneiki early harvest was 0.16, late harvest 0.11; Pendolino early harvest 0.13, late harvest 0.07. Generally, K_{270} was lower in Victoria and Western Australia than the other two growing regions (Table 3).

The mean concentration of α-tocopherol from this study ranged from 69 mg/kg oil (Manzanillo, Western Australia), to 481 mg/kg (Coratina, NSW/Qld) (Table 3). Only Coratina and Corregiolla were found to be significantly affected by growing region ($p < 0.05$). Arbequina was affected by harvest timing ($p < 0.05$), with 301 mg/kg oil at the early harvest, and 240 mg/kg at the late harvest.

Conclusion

The results from this study show that geographic location, including climate, can have a significant bearing on the quality and chemical components of olive oil. This has been shown to be the case with other oil crops as well. This information is useful for informing growers of the impact of the region of production, as well as the cultivars used will have an influence on the final product. The results show olive oil from the major cultivars grown in Australia do not meet some of the limits set by international standards for some parameters in some cases. The continued study of olive oil composition from olives grown outside the traditional Mediterranean growing regions will allow the knowledge base to expand, and the international rules governing olive oil trade to be updated to reflect this.

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