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Research Article

Response of Sunmuscat (*Vitis vinifera* L.) to Varying Cane Numbers When Managed on a Shaw Swing-Arm Trellis for Dried Grape Production

P. R. Clingeleffer and C. A. Tarr

CSIRO, Waite Campus, Glen Osmond SA 5064, Australia

Correspondence should be addressed to P. R. Clingeleffer; peter.clingeleffer@csiro.au

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Background and Aims. Dried grapes from Sunmuscat compose more than 50% of Australia's production. Sunmuscat is late ripening which can lead to suboptimal drying conditions and darkening of the final product. The response of Sunmuscat to varying cane number per vine was studied with the aim to promote earlier ripening and optimise berry size and yield, without detrimental effects on dried product quality. *Methods and Results*. The study was conducted in a trellis dried, commercial vineyard with pruning level treatments of 6, 9, 12, and 15 canes per vine over 3 seasons. It included assessment of budburst and fruitfulness in spring; monitoring of grape ripening; measurement of yield, bunch number, and moisture content at harvest; and post-harvest assessment of dry berry mass and fruit colour. Traits strongly affected by season were fruitfulness, yield, berry development, juice composition (TSS, pH, and TA), and dried grape quality (colour, dry berry mass, and sugar per berry). Retention of high cane numbers produced a slight delay in ripening (i.e., a mean of 1.1°Brix), small berries, and an asymptotic yield response without an effect on dried fruit colour or moisture. A linear response for bunch loss between spring and harvest was found with increasing cane number. *Conclusions*. Retention of fewer canes increased berry size and promoted earlier ripening, but at the expense of yield. *Significance of the Study*. Bunch loss between spring and harvest was the major yield determinant being more important than budburst, shoot fruitfulness, or berries per bunch.

1. Introduction

The Sunmuscat cultivar was released jointly by the United States Department of Agriculture (USDA) and CSIRO in 1997 [1]. It has become a significant dried grape cultivar accounting for more than 40% of total production in Australia (Dried Fruits Australia, pers comm.). Sunmuscat produces a light amber dried product with a distinct Muscat character and is used commercially as an alternative Sultana type [2]. It has also shown some promise as an alternative to the seeded, Muscat Gordo Blanco cultivar when treated with gibberellic acid (GA) to increase berry size [2]. It has also been used for the production of dried Muscatel bunch clusters and the commercial production of Moscato style wines. Sunmuscat has favourable fruit composition for hot climate wine production with low pH, good acidity, and a high tartaric to malic acid ratio [3, 4].

Sunmuscat is highly productive and rain tolerant and develops loose bunches which facilitates the application of drying emulsion for *in situ*, trellis drying [2]. It is easily managed as grafted vines on tall trellises with permanent cordons and hanging canes developed to facilitate mechanisation of Sultana production [2, 5]. The most common rootstock used for Sunmuscat across the industry is 1103 Paulsen, reflecting the superior performance of Sunmuscat on this rootstock in comparative studies with other rootstocks [5].

Early anecdotal evidence from Sunmuscat growers indicated that bunches at the ends of canes appeared to be easily stressed and produce smaller and sometimes immature berries leading to a reduction in dried fruit quality. For Sunmuscat managed on a Shaw swing-arm trellis, maturity of fruit from upper parts of the canopy was 3.0°Brix higher than for fruit from the lower part of the canopy [6]. Sunmuscat has also been shown to be susceptible to water stress [7]. Potential productivity may also be limited by its low fruit set and berry retention per bunch (10–15%) which was improved by trunk cincturing and in some seasons, by the application of the growth regulator, Cycocel® (chlorocholine chloride, CCC) [8]. Singh and Treeby [8] were also able to show increased berry retention with applications of mineral elements known to be involved in plant reproductive processes around flowering (i.e., B, Ca, and zinc) but only when competition for assimilates was moderated by cincturing. They concluded that the main cause of poor berry retention was an imbalance of the carbon supply in the grapevine leading up to flowering. The use of CCC to enhance berry set is under question due to issues with maximum residue limits in some markets (Dried Fruit Australia, pers comm.).

Compared to Sultana, Sunmuscat is relatively late ripening, reaching optimum TSS for dried fruit production of 22–24°Brix [6] in early to mid-March. Phenology data [3] show that mean date of budburst and flowering was similar for Sultana and Sunmuscat but that veraison and harvest date at 22°Brix of Sunmuscat were delayed compared to Sultana by 6 and 24 days (i.e., 24 and 30 December for veraison and 19 February and 15 March for harvest). Consequently, the cutting of canes to commence the trellis drying process at optimum maturity is later than for Sultana. Delayed cane cutting may lead to slow drying due to less favourable conditions associated with shorter days and lower temperature. Slower drying may cause difficulties in achieving acceptable moisture levels for mechanical harvest (i.e., <18%), higher dehydration costs to reduce moisture levels to 13% for delivery, and darkening of the final product, as described for Sultana [9]. Furthermore, feedback from dried fruit processors indicates that the use of GA to increase berry size increases the attachment of the "cap stem" (the dried berry pedicel) causing processing difficulties. Hence, GA treatment to increase berry size is not recommended.

In previous research, an asymptotic yield response to increasing cane number was found with vigorous Sultanas grafted onto Ramsey rootstock, grown in a hot irrigated region [10]. In that study, maximum yield was achieved with the retention of 14 and 19 canes per vine compared to 9 canes per vine. Each cane had 14 nodes. Lighter pruning produced a decrease in berry and bunch mass but had no impact on TSS. This study investigated the response of Sunmuscat to varying cane number per vine with the aim to optimise berry size and promote earlier ripening and maximize yield without detrimental effects on dried product quality and without the use of growth regulators.

2. Materials and Methods

2.1. Trial Design. The study was conducted on a commercial property located in the Mildura region in North West Victoria, Australia, over three seasons (2003/04–2005/06) with Sunmuscat managed on a Shaw swing-arm trellis system as described for Sultana. At the commencement of the study, the Sunmuscat vines grafted on 1103 Paulsen (*V. berlandieri* × *V. rupestris*) rootstock and planted in sandy loam soil were 6 years old. The vines were irrigated by undervine sprinklers using approximately 8 ML/ha of water each season and maintained according to standard industry practice with minimal tillage of the soil, application of sterilant herbicides on the undervine bank, a fertiliser program involving annual applications of 50, 5, and 25 kg/ha of nitrogen, phosphorous, and potassium, respectively, and *in situ* trellis drying of the fruit. The latter process involved cutting of canes to commence the drying process at optimum maturity (22–24°Brix) and application of an alkaline oil-in-water drying emulsion (see below) to speed up the drying process with the aim to produce a light-coloured product [9].

The site included two rows established in an east-west direction with the fruiting side of one row facing north and one facing south each alternate year, depending on the trellis management to position the fruiting canes [11]. A 3.27 m × 2.35 m row × vine spacing was used, giving 1300 vines/ha. The trellis cordon height was 1.8 m with a maximum trellis width of 1.45 m at 1.2 m from the ground when the swinging arm was locked in position. Prior to imposition of the pruning treatments, most vines were pruned with 12–15 canes of varying node numbers. The longer canes were attached by wrapping along the lower wire.

The four pruning treatments included were retention of 6, 9, 12, and 15 canes per vine with an average of 19 nodes per cane (Table 1). The trial was established as a fully randomised block design with eight single vine replicates, four in each row, in winter 2003.

Appropriate weather records were obtained from the nearby Australian Government Bureau of Meteorology Mildura weather station (076031, 34°23′S, 142°08′E) located within 3 km of the trial site.

2.2. Assessment of Fruitfulness in Spring. The Merbein Bunch Count technique [12] was used in spring in each season for all canes to provide a detailed record of % budburst, shoot and inflorescence numbers, and fruitfulness at each node, and for each treatment vine, the total number of shoots, inflorescences (bunches), and nodes per cane and per vine.

2.3. Fruit Maturation. Berry samples were collected on a weekly basis during the later stages of fruit development when TSS values were above 19°Brix, up to the commencement of drying by cane severance. At each sampling date, five berries from 20 randomly selected bunches to give a total of 100 berries were collected from each replicate vine to determine fresh berry mass. The 100 berry samples were crushed to extract juice without maceration in a plastic bag with a rubber pestle. The free run juice was then centrifuged in 50 mL tubes for 10 minutes at 1600 g using an Eppendorf 5810R centrifuge (Eppendorf AG, Hamburg, Germany). TSS

Table 1: Effect of varying cane number and season on yield components determined in spring for Sunmuscat over three seasons (2003/04–2005/06).

	Cane number				Season		
	6 canes	9 canes	12 canes	15 canes	2004	2005	2006
Canes/vine	6.25a	8.83b	11.3c	13.5d	9.91	10.3	9.66
Nodes/vine	119a	171b	211c	258d	205b	188ab	177a
Nodes/cane	19.1	19.2	18.4	18.4	19.6	18.2	18.4
Shoots/vine	119a	165b	198c	255d	203b	181a	169a
Shoots/cane	19.1	18.7	17.5	19.0	20.4b	17.7a	17.7a
Shoots/node	1.00	0.96	0.94	0.99	0.99	0.96	0.95
Bunches/vine	151a	191b	226c	280d	220b	231b	186a
2003/04	133a	190b	250c	305d			
2004/05	166a	205b	225b	327c			
2005/06	155a	177ab	204b	209b			
Bunches/cane	24.2b	21.7a	20.0a	20.7a	22.2b	22.8b	20.1a
2003/04	22.1	21.5	21.9	23.0			
2004/05	25.3	23.6	19.3	23.0			
2005/06	25.2c	20.0b	18.8b	16.2a			
Bunches/shoot	1.27b	1.18ab	1.17ab	1.10a	1.11a	1.23b	1.14a
2003/04	1.09	1.06	1.22	1.06			
2004/05	1.35	1.31	1.21	1.29			
2005/06	1.36c	1.16b	1.09ab	0.97a			

Mean values followed by different letters are significantly different ($p = 0.05$, $n = 8$) using Fisher's LSD. Interactions between treatments and season were not significant except for bunches per vine, per cane, and per shoot. In these cases, the data shown have also been analysed for each season.

of the juice sample was determined using a temperature-compensating digital refractometer (Atago Co., Japan), and pH and titratable acidity (TA) were determined using a Metrohm Titrino autotitrator (Metrohm Ltd., Herisau, Switzerland). An estimate of sugar per berry was calculated as juice TSS/100 × berry mass.

2.4. Drying and Harvest. Canes were severed for all treatments to commence drying on 10/03/2004, 9/03/2005, and 14/03/2006 to fit with the commercial operations of the grower taking into account fruit maturity and weather conditions. An alkaline oil-in-water drying emulsion consisting of 0.8% commercial drying oil (*Voullaires* EE-MULS-OYLE™) and 1.0% potassium carbonate [9] was applied to the fruiting zone to saturation by the grower with a high volume, recycling sprayer soon after cane severance. For each vine, the dried fruit was hand harvested and weighed and the dried bunches were counted (2004 and 2006 only) on 31/03/2004, 04/04/2005, and 19/04/2006. An estimate of bunch mass was calculated from the yield and bunch number data.

2.5. Assessment of Dried Fruit. At harvest, fruit from each replicate was sampled for measurement of moisture content (wet weight basis) using the industry standard moisture meter [13]. A further sample of dried fruit from each replicate was ground dried to remove excess moisture to a level of 13% [9] and then stored at 0°C to maintain fruit colour until measurements of dry berry mass and fruit colour were undertaken. An estimate of berries per bunch was calculated from the estimate of bunch mass and dry berry mass ignoring dry rachis mass. Fruit colour was measured with a Minolta Chromameter CR200 (Minolta Camera Co., Osaka, Japan) and expressed as the CIE tristimulus L^*, a^*, and b^* values [14, 15].

2.6. Statistical Analysis. The data from the randomised block design were subjected to analysis of variance using Genstat v10 (VSNi, Helensburgh, NSW, Australia). SigmaPlot 14.5 (Systat Software Inc., San Jose, California) was used to prepare the figures.

3. Results

3.1. Spring Measurements. Results from the detailed spring Merbein Bunch Count revealed significant effects of season and cane number treatment on most yield component variables (Table 1). Significant seasonal effects show that node numbers per vine were highest and lowest in spring 2003 and 2005, respectively, that shoot numbers per vine and per cane were highest in 2003, that bunches per vine and per cane were lowest in 2005, and that fruitfulness (bunches per shoot) was highest in 2004. There was no effect of season on cane number, nodes per vine, or nodes per cane, an indication that the applied treatments were consistent between seasons.

Over the three seasons, there were significant effects of cane number on all yield components, except nodes per cane and shoots per cane indicating that budburst was unaffected by cane number (Table 1). Due to limited development of replacement canes arising from the bilateral cordon on some vines, it was not always possible to retain sufficient canes at pruning to achieve the 12 cane (mean = 11.3) and 15 cane (mean = 13.5) treatments. The significant effect of cane number on shoots and bunches per vine was directly related to nodes per vine with a 2-fold increase from 6 to 15 canes per vine. Fruitfulness (bunches per shoot) decreased as cane number increased, consequently leading to a significant reduction in bunches per cane.

Interactions between treatments and season were significant for bunches per vine ($p < 0.001$), bunches per cane ($p = 0.02$), and bunches per shoot ($p = 0.02$). The highly significant treatment × season interaction for bunches per vine can be attributed to differences in magnitude of the response to varying cane number over time (i.e., a 2.3-fold difference in spring 2003; a 2.0-fold difference in 2004; and a 1.4-fold difference in 2005 (Table 1)). The significant treatment × season interaction for bunches per cane and bunches per shoot was due to the occurrence of significant treatment effects in only one season, 2005 with respective

1.6- and 1.4-fold reductions with the retention of high cane numbers (i.e., from 25.2 to 16.2 bunches per cane and from 1.36 to 0.97 bunches per shoot).

Detailed analyses of cane number treatment effects on budburst (shoots per node), bunches per shoot, and bunches per node at each node position along the cane are shown for each season in Figures 1–3, respectively. Both the pattern of budburst along the canes and the maximum values of budburst varied between seasons, whereas cane number treatments had little effect on budburst, confirming the overall results reported in Table 1. For all treatments in spring 2003, there were sharp increases in budburst from basal nodes positions reaching a maximum value of 1.4 shoots per node between nodes 7–9 and then reducing to 0.8-0.9 shoots per node for distal nodes (Figure 1). The increase in budburst along the cane from basal nodes was more gradual in the other seasons reaching maximum values up to 1.2 shoots per node in 2004, between nodes 12 and 16, and up to 1.0 shoot per node between nodes 8 and 10 in 2005.

The along the cane trends for shoot fruitfulness (bunches per shoot, Figure 2) provide an explanation for the significant treatment × season interaction presented in Table 1, leading to a trend to reduced fruitfulness with higher cane numbers over time. In spring 2003, fruitfulness (bunches per shoot) of all treatments increased from the basal nodes (range 0.7–0.9 bunches per shoot) to a maximum of 1.2 bunches per shoot at around node position 6, a level maintained until node 16. In spring 2004, fruitfulness patterns varied with cane number treatment ranging from 1.1 to 1.2 bunches per shoot at the basal positions (all treatments) to a maximum of 1.5-1.6 bunches per shoot between nodes 5 and 10 for the 6 cane treatment. Fruitfulness of the 9 cane treatment reached a maximum of 1.5 bunches per shoot at nodes 8–10 but was lower than the 6 cane treatment at nodes 4–6. At node positions 5–10, fruitfulness of the 12 cane and 15 cane treatments was lower, i.e., 1.2-1.3 bunches per shoot. Fruitfulness of all treatments tended to reduce beyond node 10. In spring 2005, the 6 cane treatment had the highest fruitfulness, at all node positions up to node 17, ranging from 1.2 bunches per shoot for basal nodes up to 1.5 bunches per shoot between nodes 12 and 16. Fruitfulness of the 9 cane treatment tended to plateau from node 6 to 17, with values between 1.2 and 1.3 bunches per shoot. Fruitfulness of the 12 cane treatment also tended to plateau, with fruitfulness ranging from 1.0 to 1.2 for nodes 6–17. Fruitfulness of the 15 cane treatment was lower than all other treatments at most node positions.

The combined effects of budburst and fruitfulness trends along the cane on bunches per node are shown for each season in Figure 3. In spring 2003, treatment responses were small and inconsistent and generally followed similar patterns. Bunches per node increased from 0.5 to 0.6 at basal nodes to a maximum of 1.6 bunches per node at nodes 6–8 for the 6 cane treatment and at nodes 9–11 for the 15 cane treatment. Bunches per node of the 12 cane treatment tended to plateau with values of 1.2-1.3 from node 5 to 18. Bunches per node of the 9 cane treatment were slightly lower than the 12 cane treatment at some node positions. In spring 2004, there were obvious treatment effects on bunches per node. Bunches per node increased from 0.8 at basal nodes to a maximum of 1.6 between nodes 8 and 14 for the 6 and 9 cane treatments, before dropping to 1.0–1.2 at distal node positions along the cane. For the 12 and 15 cane treatments, maximum bunches per node of 1.4 occurred at nodes 9-10. Bunches per node of the 12 cane treatment were lower at distal node positions than all other treatments. Treatment effects on bunches per node were even more pronounced in spring 2005. Bunches per node of the 6 cane treatment were higher at almost all node positions up to node 17 compared to the other treatments, ranging from 0.9 bunches per node at basal nodes up to maximum values of 1.5-1.6 bunches per node between nodes 7 and 16. For the 9 cane treatment, bunches per node steadily increased from 0.6 at basal positions up to a maximum of 1.5 at node 15 reducing to 1.2 bunches per node at distal positions. Bunches per node of the 12 cane treatment increased from 0.6 bunches per node at basal nodes, plateauing with values of 1.1 bunches per node between nodes 5 and 16, with a maximum of 1.4 at node 17. Bunches per node of the 15 cane treatment were

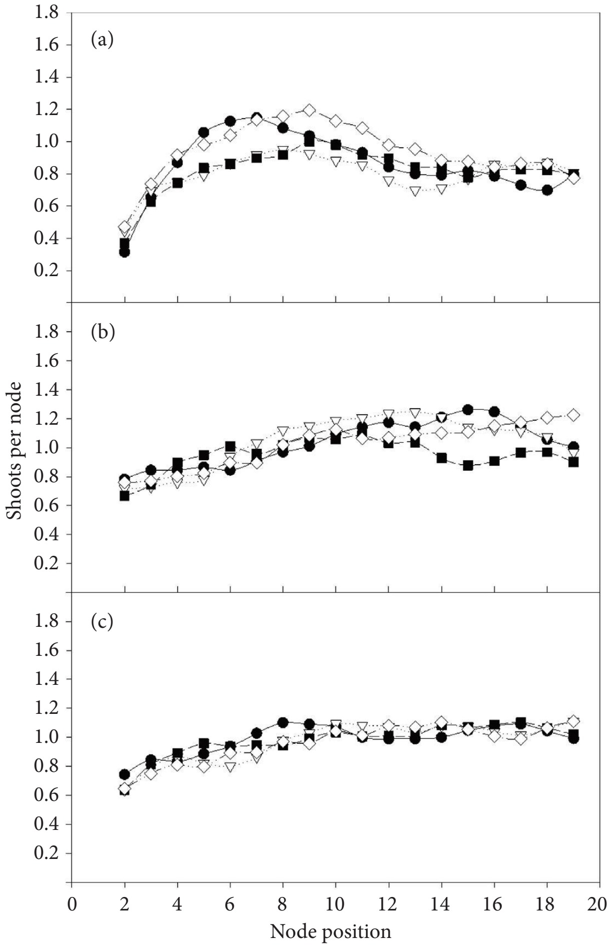

Figure 1: Changes in mean shoots per node at various node positions along the cane in seasons 2004 (a), 2005 (b), and 2006 (c) for 6 cane (●), 9 cane (▽), 12 cane (■), and 15 cane (◇) treatments. The data are presented as sliding means between adjacent nodes. $n = 8$.

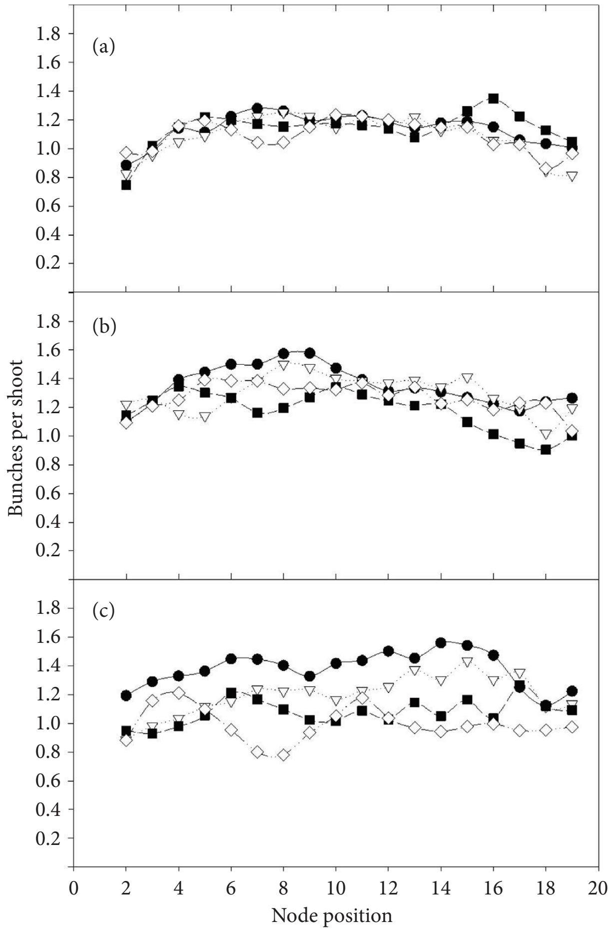

Figure 2: Changes in mean bunches per shoot at various node positions along the cane in seasons 2004 (a), 2005 (b), and 2006 (c) for 6 cane (●), 9 cane (▽), 12 cane (■), and 15 cane (◇) treatments. The data are presented as sliding means between adjacent nodes. $n = 8$.

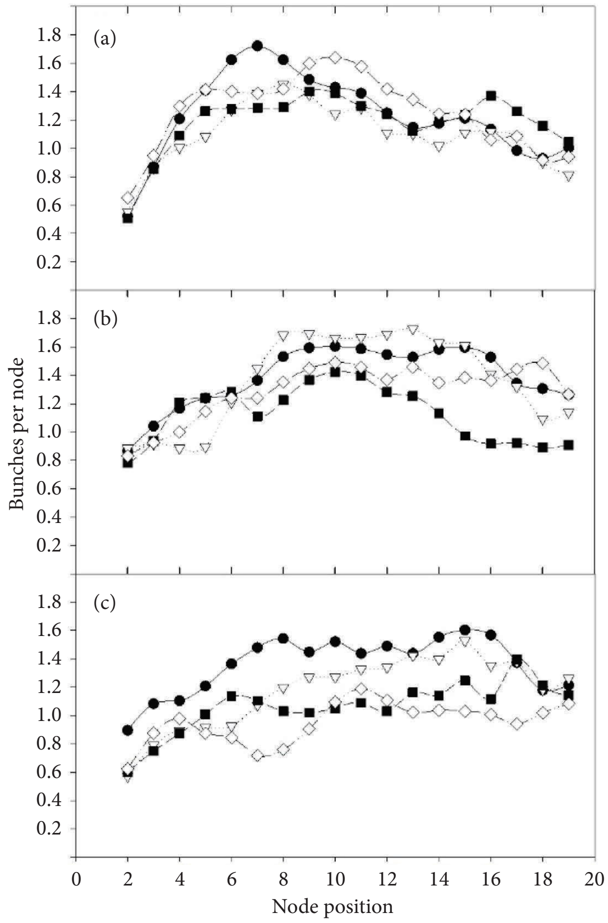

Figure 3: Changes in mean bunches per node at various node positions along the cane in seasons 2004 (a), 2005 (b), and 2006 (c) for 6 cane (●), 9 cane (▽), 12 cane (■), and 15 cane (◇) treatments. The data are presented as sliding means between adjacent nodes. $n = 8$.

lower at most node positions than the 12 cane treatment, with low values of 0.8-0.9 bunches per node at node positions 6–10 and 1.0 bunch per node between nodes 13 and 18.

3.2. Maturation. Ripening of Sunmuscat occurs over more than a two-month period, as veraison occurs at the end of December [3] while optimum sugar concentrations (TSS) for cane cutting were not reached until early March. Climatic conditions in January, during the early stages of ripening, were coolest in 2004 and hottest in 2006 with mean January maximum temperatures of 30.4, 32.4, and 36.4°C and mean minimum temperature of 14.3, 16.6, and 20.4°C in seasons 2004, 2005, and 2006, respectively. In January 2006, there were 8 days when maximum temperature exceeded 40°C. There was no rainfall in January 2004, 22.8 mm in 2005, and 4.6 mm in 2006. During the latter stages of ripening in February, climatic conditions were hottest in 2004 and coolest in 2005 with mean February maximum temperatures of 34.5, 30.3, and 32.1°C and mean minimum temperature of 17.3, 14.4, and 15.8°C, in seasons 2004, 2005, and 2006, respectively. February 2004 experienced heat wave conditions as there were 9 days when maximum temperature exceeded 40°C between the 5th and 20th February. Rainfall was very low in February in all seasons (i.e., 0.8, 3.2, and 1.2 mm in 2004, 2005, and 2006, respectively). Some rainfall did occur prior to cane cutting in early March (i.e., 0.6, 3.6, and 3.4 mm in 2004, 2005, and 2006, respectively).

Fresh berry mass was significantly impacted by season and cane number at harvest without a significant interaction (Table 2). Across the seasons, there was a 22% difference in mean berry mass with the smallest (2.22 g) and largest (2.84) berries produced in 2005 and 2006, respectively. In contrast, across the treatments, there was only a small 6% difference in berry mass, ranging from 2.63 g with 6 canes to 2.47 g with 12 canes. For all treatments in all seasons, changes in berry mass during the latter stages of ripening were small (Figure 4). At most sampling dates, the 6 cane treatment had the largest berries while the 12 and 15 cane treatments had the smallest berries.

At cane severance, there were significant effects of season and cane number on TSS (Table 2). There was a 6% difference in mean TSS between seasons, ranging from 25.5°Brix in 2004 to 23.9°Brix in 2006, the latest ripening

Table 2: Effect of varying cane number and season on fresh berry mass and composition, yield components of dried fruit at harvest, dried fruit colour, and moisture content of Sunmuscat over three seasons (2003/04–2005/06).

	Cane number				Season		
	6 canes	9 canes	12 canes	15 canes	2004	2005	2006
Fresh berry							
Fresh berry mass (g)	2.63b	2.57ab	2.47a	2.49a	2.57b	2.22a	2.84c
TSS (°Brix)	25.2c	24.8bc	24.2a	24.1a	25.5b	24.2a	23.9a
Sugar/berry (g)	0.66b	0.64b	0.60a	0.60a	0.66b	0.54a	0.68b
Titratable acidity (g/L)	7.32	7.37	7.37	7.43	6.79b	9.00c	6.32a
pH	3.58b	3.56ab	3.55a	3.54a	3.63b	3.41a	3.63b
Dried fruit							
Dried yield/vine (kg)	8.58a	9.49b	9.65b	9.97b	8.37a	10.9b	9.05a
Bunch number[1]	126a	142a	162b	170b	155	—	145
Dry berry mass (g)	0.75b	0.69a	0.68a	0.69a	0.75c	0.66a	0.70b
Fresh : dry mass ratio	3.51a	3.72c	3.63b	3.61b	3.43a	3.36a	4.06b
Bunch mass (g)[1]	57.3	58.7	55.5	53.8	55.4	—	57.3
Berries/bunch[1]	76.4	85.1	81.6	77.9	73.9	—	81.9
L value	29.4	29.6	29.6	29.8	31.8c	29.8b	27.2a
a value	4.03	4.11	4.03	4.15	2.93a	3.22a	6.09b
b value	12.9	13.4	13.3	13.7	15.8c	13.2b	10.9a
Moisture (% wet wt.)	15.3	15.0	14.9	15.1	12.4a	14.4b	18.5c

Mean values followed by different letters are significantly different ($p = 0.05$, $n = 8$) using Fisher's LSD. Interactions between treatments and season were not significant. [1]Seasons 2003/04 and 2005/06 only. $n = 8$.

season. Compared to the 6 cane treatment (mean: 25.2°Brix), retention of high cane numbers produced small, but significant reductions in TSS, i.e., up to 4% with 15 canes. The maturation curves presented in Figure 5 show that ripening in season 2004 was earlier than in 2005 or 2006 across all treatments, leading to higher TSS when canes were severed to commence drying. In contrast, TSS of all treatments in 2006 was lower prior to drying, despite the delay in cane severance. Highly significant linear regressions ($p < 0.001$) were fitted to the ripening data across cane number treatments for each season. These equations, provided below, confirm the responses reported above with TSS values on 1 February (the y intercept) of 19.3, 17.3, and 16.2°Brix in 2004, 2005, and 2006, respectively.

$$\begin{aligned} &2004\,\text{TSS}\,(^\circ\text{Brix}) = 19.31 + 0.17\,\text{days}\left(\text{adj. R}^2\ 0.86\right),\\ &2005\,\text{TSS}\,(^\circ\text{Brix}) = 17.32 + 0.19\,\text{days}\left(\text{adj. R}^2\ 0.93\right),\\ &2006\,\text{TSS}\,(^\circ\text{Brix}) = 16.23 + 0.19\,\text{days}\left(\text{adj. R}^2\ 0.92\right). \end{aligned} \tag{1}$$

Similarly, significant regressions ($p < 0.01$, adj. r values: 0.88–1.0) were also fitted to the limited ripening data for each treatment in each season (not shown in detail). In 2004, retention of higher cane numbers delayed ripening as TSS concentrations were lower at most sampling dates as cane number increased (Figure 5). The respective TSS values on 1 February were 20.4, 19.6, 18.9, and 18.4°Brix with slopes of 0.16, 0.17, 0.18, and 0.18°Brix/day for the 6, 9, 12, and 15 cane treatments. In 2005, the significant differences at harvest were related to slower rates of ripening with high cane numbers (Figure 5). In 2005, the respective TSS values on 1 February were 17.2, 17.1, 17.6, and 17.4°Brix with slopes of 0.21, 0.20, 0.17, and 0.17°Brix/day for the 6, 9, 12, and 15 cane treatments. In 2006, the 6 cane treatment had the highest and the 12 cane treatment had the lowest sugar concentrations at most sampling dates (Figure 5). In 2006, the respective TSS values on 1 February were 16.9, 15.3, 15.5, and 17.4°Brix with slopes of 0.18, 0.21, 0.15, and 0.21°Brix/day for the 6, 9, 12, and 15 cane treatments. Overall years and treatments there was a negative correlation ($r = 0.56$, $n = 12$) between TSS on 1 February (y intercept) and the rate of change in TSS (slope) indicating reduced sugar loading of berries with higher TSS.

Sugar/berry, which reflects the combined effects of berry size and TSS, increased by about 50%, in all seasons from the first sampling around 19°Brix until cane severance. At cane severance, sugar per berry was highest in 2006 and lowest in 2005 (Table 2). The 6 and 9 cane treatments had significantly higher sugar per berry than the 12 and 15 cane treatments. While differences between cane number treatments were significant, but small, the 6 cane treatment had highest sugar per berry at most sampling times in all seasons (Figure 6).

At cane severance, pH was significantly lower in 2005 compared to the other seasons while lighter pruning tended to produce lower pH, with 6 canes having highest pH and 12 and 15 canes the lowest pH (Table 2). There was a significant increase in pH from the first sampling until cane severance in all seasons ranging across the treatments from 3.05 to 3.70 in 2004, 3.20 to 3.45 in 2005, and 3.50 to 3.65 in 2006 (detailed data not shown). The 6 cane treatment (data not shown) had higher pH at most times of sampling in all seasons than the other treatments. Juice TA at harvest was unaffected by cane number but significantly impacted by season, ranging from 6.32 g/L in 2006 to 9.0 g/L in 2005 (Table 2).

3.3. Dried Fruit Yield and Fruit Characteristics. Climatic conditions were ideal during the drying period, 10–31 March in 2004, with a mean maximum temperature of 33.9°C, a mean daily evaporation of 7.4 mm, and zero rainfall over

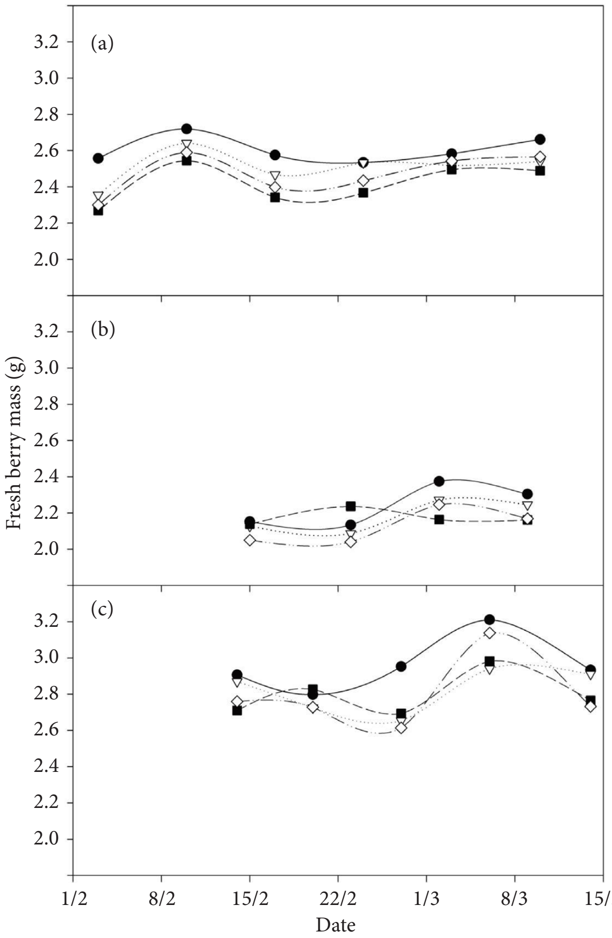

Figure 4: Changes in mean fresh berry mass (g) during fruit maturation in harvest seasons 2004 (a), 2005 (b), and 2006 (c) for 6 cane (●), 9 cane (▽), 12 cane (■), and 15 cane (◇) treatments. Respective LSD values ($p = 0.05$) for significant differences between sample dates were 0.071, 0.076, and 0.142 and for those between treatments were 0.058, 0.076, and 0.127 in 2004, 2005, and 2006, respectively. The date × treatment interactions were not significant in any year.

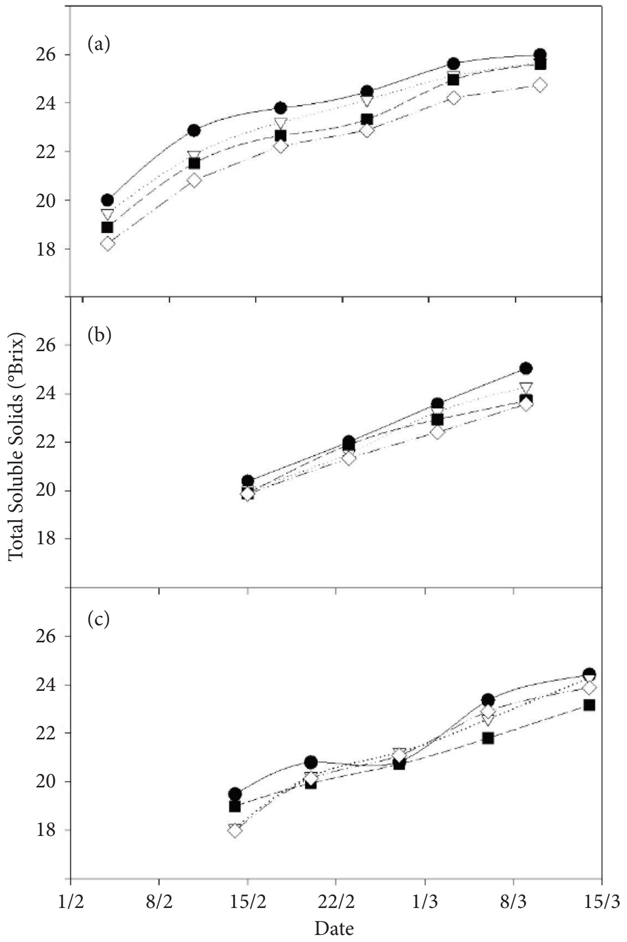

Figure 5: Changes in total soluble solids (TSS, °Brix) during fruit maturation in harvest seasons 2004 (a), 2005 (b), and 2006 (c) for 6 cane (●), 9 cane (▽), 12 cane (■), and 15 cane (◇) treatments. Respective LSD values ($p = 0.05$) for significant differences between sample dates were 0.484, 0.446, and 0.600 and for those between treatments were 0.396, 0.446, and 0.536 in 2004, 2005, and 2006, respectively. The date × treatment interactions were not significant in any year.

the 21-day period. Although slightly cooler, climatic conditions were also favourable for the drying period, 9 March–4 April in 2005, with a mean maximum temperature of 28.5°C, a mean daily evaporation of 7.4 mm, and zero rainfall over the 26-day period. In contrast, climatic conditions for drying in 2006 were poor, leading to an extended period of drying (14 March–19 April) associated with low mean maximum temperature (24.9°C), low mean daily evaporation of 5.4 mm, and significant rainfall events, totalling 28.6 mm with 6.6, 14.0. 3.6, and 3.2 mm on 16 and 28 March and 15 and 18 April, respectively.

Dried fruit yield varied significantly by 30% between seasons being highest and lowest in 2005 and 2004, respectively (Table 2). Over the seasons, the 6 cane treatment had significantly lower yield than the other treatments (i.e., 14% less than the highest yielding 15 cane treatment). There was no difference in the number of bunches at harvest between the two seasons they were measured. The 12 and 15 cane treatments had significantly higher bunch numbers than the 6 and 9 cane treatments, with a 26% difference between the lowest 6 cane treatment and the highest 15 cane treatment. Effects of season and cane number on dry bunch mass were not significant although the negative trend to develop smaller bunches with increasing cane number was significant ($r = -0.83$, $p < 0.05$).

There were significant reductions in the number of bunches retained from the detailed counts in spring (Table 1) through to harvest (Table 2) in the 2 seasons bunch numbers were recorded at harvest, i.e., retention of 71% and 78% of the inflorescences in 2004 and 2006, respectively, indicating significant abortion or lack of bunch development. Furthermore, as cane numbers increased, the retention of bunches decreased linearly with retention of 89%, 73%, 69%, and 62% in 2004 ($r = -0.95$) and 85%, 82%, 74%, and 72% in 2006 ($r = -0.97$) for the 6, 9, 12, and 15 cane treatments, respectively.

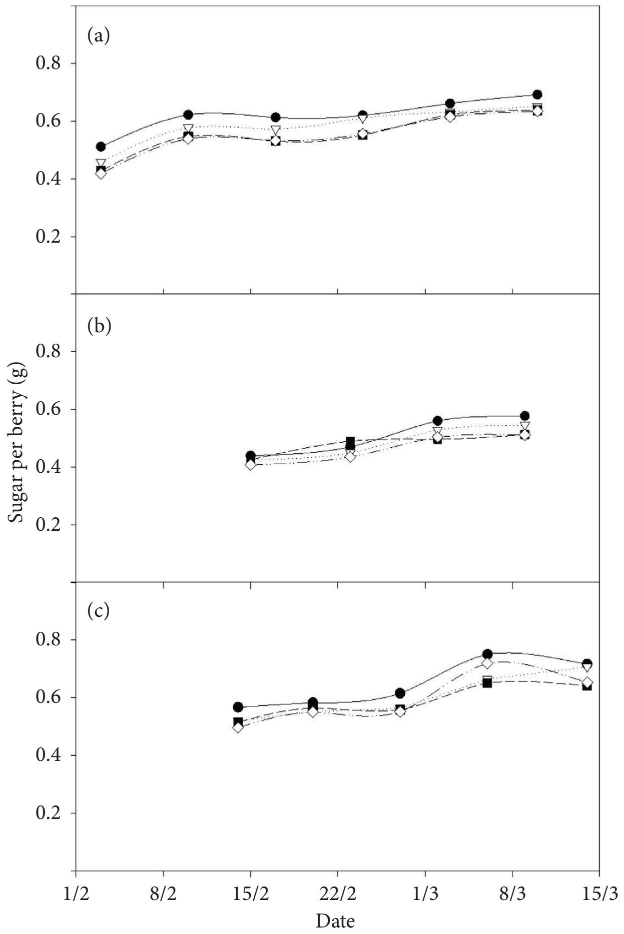

Figure 6: Changes in sugar per berry (g) during fruit maturation in harvest seasons 2004 (a), 2005 (b), and 2006 (c) for 6 cane (●), 9 cane (▽), 12 cane (■), and 15 cane (◇) treatments. Respective LSD values ($p = 0.05$) for significant differences between sample dates were 0.022, 0.022, and 0.036 and for those between treatments were 0.018, 0.022, and 0.033 in 2004, 2005, and 2006, respectively. The date × treatment interactions were not significant in any season.

Dry berry mass differed by 14% between seasons with the largest and smallest dried berries produced in 2004 and 2005, respectively, reflecting the combined effects of differences in both the fresh berry mass and sugar content (Table 2). Over seasons, the 6 cane treatment had 10% significantly larger dry berries than the other treatments. There was no significant effect of cane number on berries per bunch, calculated from berry and bunch mass (Table 2). There were significant differences in the drying ratio (berry fresh mass/dry mass) between seasons, being highest in 2006 when TSS concentrations were low. The 9 and 6 cane treatments had the highest and lowest drying ratios, respectively.

Dried fruit colour and moisture were unaffected by cane number treatments (Table 2). Significant differences between seasons in *L* value show that the lightest and darkest fruit was produced in 2004 and 2006, respectively. Compared to the other seasons, the high a value in 2006 indicates the production of redder fruit. Significant differences in b value show that the dried fruit was the most and least yellow in 2004 and 2006, respectively. The production of the dark, red, and least yellow fruit in 2006 can be attributed to the poor drying conditions, particularly the number of rainfall events leading to slower drying. As a consequence, the fruit was also harvested with a high moisture content compared to 2004 and 2005.

4. Discussion

4.1. Effect of Season on Components of Yield. This study has confirmed that Sunmuscat has the capacity to produce very high yields of dried grapes, with a mean of 13 t/ha over 3 seasons, ranging from 10.9 to 14.2 t/ha. These yields equate to 44 t/ha of fresh grapes (range: 37–48 t/ha) calculated from the fresh to dry mass ratio (Table 2). These high yields are comparable to those reported previously in studies comparing trellis configurations [2] and rootstock types [5].

The 30% variation in yield between seasons, highest in 2005 (Table 2), was not related to differences in node number per vine or budburst, but largely by bunches per vine which in part can be accounted for by differences in shoot fruitfulness (11%) in spring (Table 1) and bunch loss between spring and harvest (Tables 1 and 2). The mean fruitfulness value, however, must be treated with caution because of the impact of the season × cane number treatment interaction on shoot fruitfulness which showed a reduction in fruitfulness over time with higher cane numbers (Table 1). Differences in the retention of bunches from spring to harvest (71% in 2004 and 78% in 2006), however, appear to be the critical factor contributing to yield variability between seasons, although this could not be confirmed in season 2005 (Tables 1 and 2). While there was no difference in dry bunch mass in the two seasons measured, it is also possible that the high yield in 2005 could have been associated with the development of larger bunches with more, but smaller berries (Tables 1 and 2). In a previous study, fresh yield variation of Sunmuscat over 9 seasons was associated with both bunch number (58%) and bunch mass (38%), reflecting differences in berries per bunch [2]. Differences in TSS and the impacts on the drying ratio [16] would also have contributed to differences in dry yield between seasons. In this study, the drying ratio value was higher in 2006 compared to the other seasons, a response associated with the low TSS in that season. This study reports the combined effects of north and south canopy and fruit exposure. In a related study, there were no significant effects of canopy and fruit exposure on budburst, fruitfulness, yield, and fresh berry mass [6].

This is the first study to assess fruitfulness of Sunmuscat in detail. Over the three seasons, budburst of Sunmuscat was consistently high (0.95–0.99%) and burst shoots were highly fruitful with 1.11–1.23 bunches per shoot (Table 1), an indication that fruitfulness as a determinant of yield is less important than for Sultana, the main drying cultivar historically grown in Australia. For Sultana, significant differences in shoot fruitfulness (0.3–0.7 bunches per shoot) have been linked to yield variation between seasons [11, 17–20]. Fruitfulness of Sultana has been linked to climatic conditions during bunch primordia initiation in the previous season [19, 21]. Baldwin [21] reported a 20-day "sensitive period" for inflorescence initiation in Sultana, from mid-November to early December, during which bright sunshine and maximum temperature were most significant factors in the determination of bud fruitfulness. Similar sensitive periods have been reported for other varieties of wine grapes including Riesling [22] and Chardonnay [23]. While it could be expected that Sunmuscat would have a similar sensitive period, longer term studies are required to confirm such relationships. It should be noted that mean monthly maximum temperatures in November and December 2003, when inflorescence initiation for the 2004/05 season would have occurred, were the highest recorded during the study (i.e., 29.9°C and 32.4°C, respectively, compared to 29.8°C and 32.0°C in 2002 and 27.4°C and 30.3°C in 2004). Sunshine hours were also high in November and December 2003 (i.e., 10.7 in both months compared to 9.9 and 10.6 in 2002 and 10.0 and 11.0 in 2004). It is also likely that the development of the inflorescence primordia may have been influenced by seasonal factors affecting carbohydrate concentrations in buds and dormant canes as reported for Sultana [19, 20].

Quite clearly in this study, the loss of bunches from spring to harvest appears to be a more critical factor impacting on seasonal yield variability and warrants further investigation. The occurrence of this phenomenon is rarely reported. Clingeleffer et al. [24] demonstrated loss of bunches over 3 seasons (1998–2000) with lightly pruned high yielding wine grape varieties (Chardonnay, Cabernet Sauvignon, and Shiraz) in some vineyards in the same region as this study. With vigorous, high yielding Sunmuscat vines, it is likely that this phenomenon is linked to competition of developing inflorescences with rapidly growing shoots for carbohydrate assimilates before, during, and after flowering as shown for berry set [8]. There is the strong possibility that bunch loss may be associated with severe bunch stem necrosis which has been associated with water stress, excessive N, low mineral status, excessive shade, and competition for carbohydrates [25]. Keller and Koblet [26, 27] concluded that carbohydrate starvation was a key factor in inflorescence necrosis. Champagnol [28] described a process "Filage" where inflorescences revert to tendrils in the two-week period prior to anthesis which has been linked with rapidly growing vigorous shoots and high temperatures. For Sunmuscat, Singh and Treeby [8] demonstrated that flowers and berries competed poorly with the growing shoot for assimilate, leading to reduced fruit-set and post-set berry abscission. Treatments that ameliorated this competition, e.g., cincturing and application of Cycocel® (an inhibitor of gibberellic acid synthesis) which causes shoot growth to cease, resulted in more berries per bunch at harvest. There is also the possibility that some bunch loss may have been associated with the cessation and death of some shoots associated with competition for carbohydrates. Further research is required to enhance the understanding of bunch loss between spring and harvest, particularly in respect to timing of abortion events, competition between developing bunches and shoots for assimilates, and potential treatments to ameliorate bunch losses.

4.2. Effect of Cane Number on Components of Yield. Dried fruit yield was less impacted by cane number treatments than by the effects of season. Mean dry yield of the cane number treatments over seasons varied by only 16%, from 11.1 to 13.0 t/ha, despite the 2.5-fold differences in node retention at pruning. This indicates that Sunmuscat performance is very "plastic" with self-regulation of cropping levels to the vines' "capacity," most likely driven by the supply of assimilate. Antcliff et al. [29] conducted a similar study over 3 seasons with own rooted Sultana, with varying cane numbers, i.e., from 3 to 8 canes per vine. With lighter pruning, they found a linear increase in yield and bunch number accompanied by a decrease in budburst, shoot fruitfulness, sugar content, and the number of nodes matured. Antcliff [30] in studies with low and high yielding Sultana vines also reported linear relationships between yield and cane number but no effects on sugar content. He also reported that there were no detrimental carryover effects from season to season or long-term effects from lighter pruning. In this study with highly vigorous, grafted Sunmuscat vines, a strong asymptotic yield response was found with higher cane numbers as differences between 9, 12, and 15 cane treatments were not significant. Similar asymptotic responses in the same environment have been found for Sultana grafted on Ramsey rootstock [10] and Cabernet Sauvignon with retention of longer canes, 2- bud spurs to 14 bud canes [31]. In common with Antcliff et al. [29] and Greven et al. [32, 33], both mature cane development (Table 1) and TSS (Table 2) were reduced with lighter pruning in this study.

The major adaptive processes in the self-regulation of the crop with lighter pruning in this study were a 6–10% reduction in the number of canes available for the 12 and 15 cane treatments; a reduction in bunches per cane associated with reduced fruitfulness, particularly in year 3 (i.e., 36%, Table 1); increased loss of bunches between spring and harvest (i.e., a 38% reduction in bunches with the 15 cane treatment compared to 11% reduction with the 6 cane treatment); and a 9% reduction in the dry mass of berries associated with reduced sugar per berry attributed to the development of smaller fresh berries with lower TSS (Table 2). Budburst was unaffected by cane number treatment (0.98 shoots per node), and hence shoot numbers increased with the retention of higher cane numbers. This was unexpected as previous studies involving light pruning treatments showed reduced budburst with increasing node number per vine (for example, [31, 32]). In the seasons that bunch numbers were recorded at harvest, there was a linear correlation between cane number and the loss of bunches ($r = 0.88$). To the best of the authors' knowledge, this is the first report of such a response to lighter pruning treatments. Although flower numbers were not counted, fruit set appeared to be unaffected by cane number as all treatments had similar number of berries per bunch (Table 2). In agreement with this study, Singh and Treeby [8] found that yield had no effect on berries per bunch of Sunmuscat.

4.3. Patterns of Budburst and Fruitfulness along the Cane. There was no effect of budburst on overall vine performance between seasons or cane number treatments (Table 1), although there were obvious differences between seasons in both the pattern of budburst along the cane and the maximum value attained (Figure 1). Except for the very basal nodes, the very uniform budburst along the cane indicates that acrotony, the stimulation of budburst near the pruning cut and suppression along the cane [34], was not a factor for Sunmuscat pruned with long canes (mean: 19 nodes, Table 1) which were attached to wires well below the cordon. This may be attributed to the fact that pruning cuts were possibly not made on the longer canes [35], that the more distal nodes were not fully lignified and low in carbohydrate [20], or that apical dominance of higher shoots had an impact as shown for arched cane Sultana vines [36]. The uniformity of budburst and absence of acrotony contrast to that reported for Sultana [20, 36]. The latter study was conducted under similar management practices to this study.

The along cane trends for shoot fruitfulness (Figure 2) were impacted by both season and cane number treatment, particularly in season 3 (spring 2005). Sunmuscat had higher shoot fruitfulness at all node positions than those reported for Sultana managed similarly [20]. For Sultana, nodes 7–10 tended to be the most fruitful, whereas for Sunmuscat, nodes 6–16 tended to potentially be highly fruitful but also impacted by cane number treatment. The relatively high fruitfulness of basal nodes (0.7–1.2 bunches per shoot), depending on season, indicates that Sunmuscat could be spur pruned for table grape production or mechanically hedged for wine production [4] as the values were similar to those reported for a range of table grape and wine cultivars [37]. The changes in fruitfulness attributed to lighter pruning over time showed that the 6 cane treatment had higher fruitfulness at most node positions in the third season than other treatments (Figures 2 and 3). In contrast, the 15 cane treatment had lowest fruitfulness at most node positions in that season. Fruitfulness of the 9 cane and 12 cane treatments more closely aligned to the 6 and 15 cane treatments, respectively. These responses over time are likely to be associated with the development and selection of lower quality canes, as described for Sultana [38] to ensure sufficient cane numbers and competition for assimilates [20].

4.4. Ripening and Fruit Composition. The monitoring of berry mass or maturity was not undertaken during early berry development and only commenced when TSS was around 19°Brix, well after veraison. The results presented in Figures 4–6 indicate the large effects of season and smaller effects of cane number on berry mass, and maturity and sugar per berry were already established prior to the commencement of sampling. In the case of TSS, predicted mean values of 19.3, 17.3, and 16.2°Brix on 1 February for seasons 2004, 2005, and 2006, respectively, showed that ripening was the most advanced in 2004 and most delayed in 2006. Across seasons, the rate of ripening, determined as changes in TSS during the sampling period, was relatively constant with mean values of 1.2-1.3°Brix per week despite the quite large differences in climatic conditions, for example, differences in mean maximum January and February temperatures of 30.0–36.4°C and 30.3–34.5°C, respectively. Further research is required to identify if the seasonal effects on the time of harvest were due to differences in the timing of veraison or differences in the rate of ripening post-veraison prior to commencement of sampling.

The effect of cane number on ripening was not consistent across seasons. In 2004, the delay in ripening as cane number increased was established prior to the commencement of sampling, but the rate of ripening was unaffected despite experience heat wave conditions in mid-February. In contrast, in 2005, lower maturity at harvest was associated with slower ripening rates as cane number increased. In 2006, the effects of cane number were not consistent with the 12 cane treatment having the lowest TSS at harvest associated with the lowest rate of ripening. Heat wave conditions in January 2006 did not appear to affect ripening at the later stages of berry development but may have influenced early berry ripening leading to the lowest TSS predicted on 1 January and at the commencement of sampling. Greven et al. [33] reported that light pruning treatments with Sauvignon Blanc had no effect on the timing of veraison but delayed harvest due to slower rates of ripening. They also found that these effects were reduced over 4 seasons as differences in yield between the pruning treatments reduced over time.

Differences in sugar per berry between seasons were associated largely with the differences in berry mass and to a lesser degree, TSS (Table 2). In contrast, the 50% increase in sugar per berry from the first to the last sampling point across seasons and treatments was, in the main, associated with changes in TSS resulting from movement of sugar into the berry while berry mass remained relatively constant. While the small effects of cane number treatment on berry mass are most likely driven by competition for assimilates, further research is required to identify the underlying causes for the large differences in berry mass between seasons (22%, Table 2), particularly during the early stages of development and the timing of veraison leading to differences in earliness between seasons. The significant differences in fresh berry mass and TSS and hence sugar per berry of the 6 and 9 cane treatments are likely to be due to reduced competition for carbohydrates associated with the fewer berries per vine (i.e., 11,440, 13,750, 14,200, and 14,660 berries per vine calculated from the dry yield and dry berry mass for the 6, 9, 12, and 15 cane treatments, respectively). Further research to study the effects of crop load (i.e., the leaf area to yield ratio) on individual shoot and bunch development, ripening, and berry development would add significant value to the understanding of crop development of Sunmuscat.

Differences in pH between seasons (3.41–3.63) were associated with differences in TA (6.32–9.00 g/L) (Table 2) rather than maturity (TSS). In the late ripening 2006 season, despite the low TSS, a high pH was recorded. Clingeleffer and Davis [4] found that cultivars with delayed ripening and low TSS tended to have high pH. In contrast, the significant effect of cane number on pH was highly correlated with both TSS ($r = 0.97$) and yield ($r = -0.99$), the latter being highly correlated with TSS (−0.93). Such results indicate that the effect of cane number on pH was associated with crop load and impacts on ripening and carbohydrate partitioning. Further research into seasonal effects on pH and TA warrants further investigation. It should be noted that results from a related study show that the south exposure had lower TSS than the north exposure but that pH and TA were unaffected [6].

The fruit composition data also support the use of Sunmuscat for wine production when grown in a hot climate, in this case grafted on 1103 Paulsen. Samples collected at around 22°Brix had very acceptable composition for wine with pH values between 3.4 and 3.6 and high concentrations of TA, 6.5–9.0 g/L. Clingeleffer and Davis [4] reported that the high TA of Sunmuscat was associated with a high tartaric acid (6.4 g/L) and low malic acid (3.4 g/L) giving a high tartaric to malic acid ratio of 2.1. The fruit composition data compare very favourably with other Muscat varieties grown in a similar environment, including the dominant cultivar used for wine, Muscat Gordo Blanco which had very high pH (4.29), low TA (2.6 g/L), and a low tartaric to malic acid ratio of 1.47 [3, 4].

4.5. Dried Grape Quality. The large differences between seasons in dried fruit colour with development of darker brown fruit in 2006 compared to earlier seasons are consistent with reported effects of slower and extended drying associated with low evapotranspiration and effects of rainfall which have been reported for Sultana [9]. Fruit darkening is known to be associated with enhanced polyphenol oxidase activity [39, 40] although commencement of nonenzymatic browning which occurs during storage may also have occurred [41, 42]. In this study, dried grape quality data from the north and south canopy/fruit exposure have been combined. In a related study [6], dried fruit from the south exposure had lower sugar/berry and dry berry mass, was slightly greener (*a* value), and had higher moisture, but there was no effect of exposure on dried fruit lightness (*L* value) or yellowness (*b* value).

The dried Sunmuscat product is recognised for its "plump, full bodied" berry characteristics. The study has shown potential to enhance dried Sunmuscat berry mass by about 10%, promote earlier ripening, or achieve higher TSS by reducing cane number without an effect on fruit colour or acidity, however at the expense of a 11% reduction in dry yield. Furthermore, the seasonal variability in dry berry mass (i.e., 0.66–0.75 g) suggests that a larger berried product may not be achieved every season. The drying ratios across seasons and pruning treatments, which can be attributed to differences in TSS, are similar to those reported for Sultana at similar TSS concentrations [16]. If a strategy of severe pruning was implemented to increase dry berry mass and develop a unique large-berried product, it would be necessary to provide the grower with a bonus to compensate for the yield loss.

5. Conclusion

The study has shown that retention of higher cane numbers for Sunmuscat produced higher yields and smaller dried berries without significant effects on fruit colour. Adoption of fewer canes can be used to increase berry size, enhance TSS, and promote earlier ripening to a certain degree, but at the expense of yield. For many of the traits measured, effects of season were larger than the effects of cane number. Traits strongly affected by season were fruitfulness, yield, berry mass, earliness, berry composition (i.e., TSS, pH, and TA), and aspects of dried grape quality including dry berry mass, sugar per berry, and the drying ratio. Further research is required into factors contributing to yield variability between seasons including effects of environmental factors on shoot fruitfulness; causal factors contributing to the significant reduction in shoot fruitfulness when high node numbers are retained at pruning; causal factors contributing to the significant abortion of inflorescences between counts in spring and bunch numbers at harvest; and the effects of seasonal conditions on berry development, ripening, and berry composition of Sunmuscat. In this study, long canes with high node numbers were retained (mean: 19 nodes). Further research is required to assess impacts of cane length on productivity, fruit composition, and dried fruit quality.

Data Availability

Data are available on request from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the research and publication of this paper.

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