Producing high value dried grapes

Literature Review

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Karl Sommer

Contents

List of Figures

List of Tables

1 Background

Growers in Australia have long been striving to produce dried Sultanas of golden light colour. Its consistent production first became an issue in the early sixties when there was a rising demand for light coloured fruit on the export market which was associated with a price premium to producers (Grncarevic & Lewis, 1976). Light fruit still attracts such a premium today but there has been a severe lack of a consistent supply in recent years. A variety of reasons for the shortfall have been suggested. For example, a rise in adverse weather conditions over recent years, possibly exacerbated by a shift away from rack drying toward trellis drying and full mechanisation. Another suggested reason is higher yields with bigger and denser bunches due the use of vigorous rootstocks and a maximisation of agronomic inputs like nutrition and irrigation.

The ongoing shortage of sufficient light coloured dried vine fruit (DVF) prompted the industry to commission a short review of historical and current research with respect to the underlying physiological and chemical processes that predispose grapes to browning and give recommendations on a course of action (Treeby, 2013).

After considering the initial review the industry recommended to include additional areas of interest previously not covered, including issues in relation to emulsion formulation and application as well as aspects of vine climate and canopy management. The aim is to identify possible shortcomings in the current methods and, if possible, propose solutions either through immediate action or through additional research. This review will make reference to the recent review where appropriate rather than revisit the same areas in detail.

2 Introduction

Berry dehydration, is guided by the opposing forces between the physical and chemical composition of the berry skin and the drying capacity of the surrounding atmosphere or climate. The drying process, attempts to overcome these opposing forces with the aim to achieve a maximum drying rate and optimal fruit quality. The various factors that constitute the climate and its influence on grape drying will be the initial focus of the review.

3 Climate

Climate is a summary term for the weather conditions prevailing in an area in general or over a long period. Macroclimate is a further sub-division specific to the atmospheric conditions of a region and meso- and microclimate specific to that of a vineyard or of a group of vines.

3.1 Macroclimate - regional weather

Regional weather includes variables like temperature, rainfall, wind and solar radiation, all important determinants of the evaporation rate which represents the drying capacity of the atmosphere through the absorption and transport of moisture and strongly governs berry drying rate.

3.1.1 Temperature

Hot and dry weather through the drying period from mid February to mid April is a precondition of drying grapes successfully (Whiting, 1992). The Mildura-Riverland region, where most of the dried fruit in Australia is produced, is classified as a hot or very hot region (Smart & Dry, 1980) and is considered suitable for the production of dried fruit.

The drying rate of grapes closely follows the evaporation rate for a particular region or season and there is a close correlation of drying rate with temperature and relative humidity. Both variables can be used to predict whether a product can be dried to the required moisture level under the prevailing weather conditions (Szulmayer, 1973).

A rapid drying rate is of particular importance during the early stages of drying to prevent non-enzymatic browning (Martin & Stott, 1957).

3.1.2 Solar radiation

Solar radiation has a direct influence on berry temperature of sun exposed fruit still growing on the vine, or as drying fruit, either on the rack or on the vine. The effect is apparent in rack drying fruit when there are considerable temperature differences between exposed fruit on the western side in the afternoon and fruit on the eastern side during mid morning (Szulmayer, 1973).

Berries absorb the radiant sunlight which is stored as heat depending on the amount of energy received and duration of exposure. Drying conditions become much less favourable toward the end of the drying period in April, when solar radiation and evaporation rate (Table 1) decline sharply (Wilson, 1962).

The heating effect of direct radiation is most apparent in fruit drying in trays on the ground where the temperature of exposed berries at midday may reach well over 60 °C while ambient air temperature is only between 35 – 40 °C (Christensen & Peacock, 2000).

The differential between ambient and berry temperatures is much less for grapes drying on the vine (Christensen & Peacock, 2000). This is probably because more air is flowing around berries and bunches suspended on the vine as compared to berries arranged in wooden boxes on the ground where the air is relatively still.

Records of the temperature profile of trellis drying berries in various positions on the vine as well as inside and outside bunches would be useful to assess positional effects within the trellis as well as trellis orientation and to quantify the effect of management interventions like leaf stripping and vineyard floor management. They would also allow to quantify the drying progress in relation to general weather records which in turn might be useful in predicting drying progress.

Table 1: Monthly average maximum temperature, rainfall, solar radiation and potential evapotranspiration at Mildura, 1950 - 2012.

Month	Max temperature (°C)	Rain (mm)	Radiation (W m^{-2})	Evaporation (mm)
Jan	32.3	26.2	26.2	10.3
Feb	31.7	23.9	23.9	9.4
Mar	28.4	20.1	20.1	7.1
Apr	23.6	15.1	15.1	4.5

3.1.3 Rain

Paucity of rain is a precondition for successfully drying grapes as rain can lead to berry splitting and subsequent fungal infection in maturing grapes of susceptible varieties (Grncarevic & Lewis, 1976). The average rainfall of the Sunraysia district during the drying period is not excessive but rain events are equally probable throughout the drying period (Table 1).

In Sunraysia rain events strongly influence Sultana production and quality. For example, between 1925 and 1970, harvest rainfall accounted for 81% of the variation in the total production of Sultana (Considine, 1973). Trellis drying is unlikely to improve these probabilities because, relative to rack drying, fruit remains on the vine after cutting and can't be protected with covers.

During periods of high relative humidity such as after rainfall or at night, berries may regain all the moisture lost during the previous day (Szulmayer, 1973). This is of particular concern late in the drying season due to shorter days and rising relative humidity at night.

Significant rain during drying is probably the single most detrimental factor in achieving mature trellis dried fruit of light colour. Anticipating rain events well in advance is therefore critical if damage to fruit is to be prevented or minimised. Modern day short and medium term weather forecasts have reached a high level of accuracy and are essential for planning and deciding crucial operations around trellis drying.

3.2 Microclimate - canopy climate

Canopy microclimate refers to the specific environment of a row of vines or a single vine and is often mentioned in the context of canopy management and how certain management decisions interact with the canopy microclimate and vine productivity.

Temperature, light (solar radiation) and relative humidity constitute the main elements of the canopy microclimate with an important influence on vine productivity, fruit quality and colour formation during berry development and drying.

3.2.1 Light and temperature

Fruitfulness and productivity It is well documented that the light and temperature environment within the grape canopy influences the fruitfulness of Sultana (Baldwin, 1964; May, 1965) and similar relationships have been documented for other grape varieties (Alleweldt, 1964). It is the reason why non-fruiting replacement canes on the sloping swing-arm trellis are trained in a sun-exposed position (Hayes et al., 1991).

An inherently lower fruitfulness is normally seen on Ramsey grafted, relative to ungrafted Sultana, and is possibly due to a more shaded environment around the replacement canes of grafted vines during fruit bud initiation (Sommer et al., 2000). The tendency may be overcome with a modern trellising system like the Shaw trellis, but in a traditional T-trellis the shading within grafted vine canopies may compromise fruitfulness (Sommer et al., 2001).

The relatively limited fruitfulness and high vigour of Ramsey grafted Sultana indirectly influences its trellis drying characteristics in that both factors contribute to the production of large, dense bunches with big berries which are difficult to cover and penetrate with drying emulsion and are likely to dry slowly.

Phenolic compounds like flavonols and anthocyanins The substances largely responsible for colouring of grapes are phenolic compounds. Depending on their basic chemistry phenolics are often divided in either flavonoids or non-flavonoids. Flavonoids are the largest group of phenols (4500 different compounds) and include those that contribute to the browning of fruit (Downey et al., 2006).

The level of fruit exposed to the sun during development and ripening influences the synthesis of flavonol, a flavonoid found in red and white grapes. Flavonols may be almost absent in shaded fruit but strongly increase in exposed fruit (Downey et al., 2006).

Flavonoids are produced in epidermal grape cells of the berry skin of red and white grapes. Their production is induced after exposing berries to short wave radiation beyond the visible spectrum (UV-A and UV-B) (Kolb et al., 2003). It is believed that the flavonoids act as a sunscreen by dissipating high energy radiation like UV-A and UV-B and thus protect the cell metabolism from radiation and heat damage.

There is indirect evidence to suggest that a similar mechanism exists in Sultana grapes and other dried grape varieties and direct evidence that fruit of Sultana and Merbein Seedless grown in the sun dries darker than fruit grown in a naturally shaded position (Uhlig, 1998; Uhlig & Clingeleffer, 1998a,b; Clingeleffer et al., 2003).

Fruit growing in a sun exposed position is likely to dry significantly darker than fruit growing in a shaded position.

3.2.2 Air circulation relative humidity

Wind and relative humidity are further elements of the vineyard microclimate that influence drying conditions. Good air circulation is of particular importance after rain when it may strongly accelerate drying. There are few reports in the literature applicable and relevant to trellis dried fruit production.

Air circulation was found to decrease with distance from the end post into the vineyard leading to a higher temperature and humidity (Christensen & Peacock, 2000).

Vine spacing and trellis configuration have an impact on the potential for air circulation within and between vine rows. A low traditional T-trellis with dense foliage is more likely to impede air flow than a tall swing-arm trellis that facilitates air flow under the vines and between vine rows. Regular skirting of the leaf canopy will further assist air flow between vine rows.

4 The physiology of browning

Much of the research concerned with browning of dried grapes has focused on phenolic based *enzymatic* browning mediated by the enzyme polyphenol oxidase (PPO) and to a lesser extent on *non-enzymatic* Maillard browning involving amine groups and reducing sugars.

4.1 Enzymatic browning - polyphenol oxidase (PPO)

PPO is widespread in plants and is the main cause for browning of fruit. PPO uses oxygen from the air to form dark pigments with phenolic plant compounds. In healthy plant tissue PPO is separated from tissues containing phenolics. Browning will only occur when the enzyme comes into contact with the phenolics, typically, when plant membranes separating PPO from the phenolics become disrupted either through physical injury or during senescence (Frank, 1995).

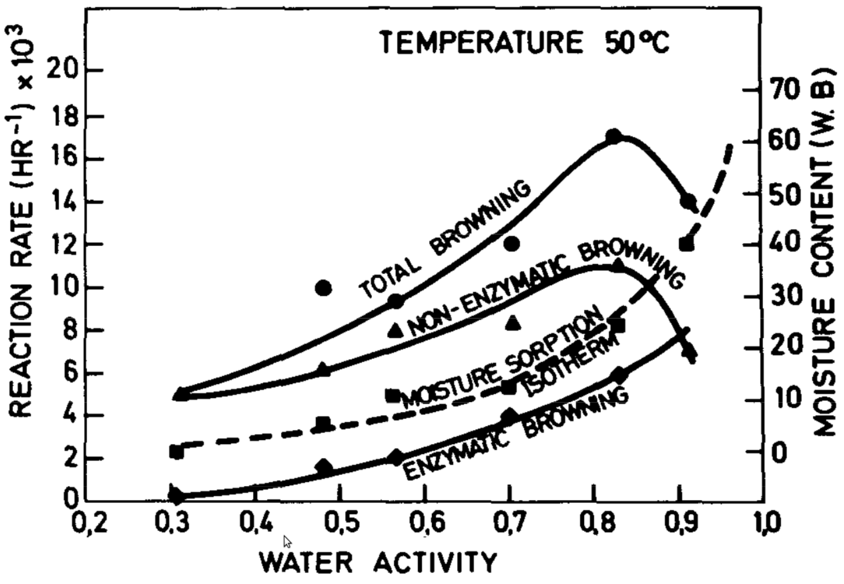
There is a close positive correlation between the residual levels of PPO and the degree of browning after inactivating PPO by immersing berries in hot water (83 – 98 °C) although PPO never appears to be completely deactivated at those temperatures (Aguilera et al., 1987). Heating to a lower temperature with a maximum of 60 °C gave raisins of varying degree of brown colour probably because of incomplete deactivation of PPO (Bingol et al., 2012).

The activity of PPO is strongly influenced by the moisture content or water activity in the prevailing environment (Aguilera et al., 1987, Figure 1). This explains why immature berries, with a relatively low sugar concentration, darken more easily after emulsion treatment than more mature berries (Radler, 1964). The higher sugar concentration but lower water content and water activity of mature, relative to immature berries, more quickly inhibits PPO after emulsion treatment and thus limits browning (Grncarevic & Hawker, 1971).

The Sultana clone Bruce's Sport naturally has a reduced browning capacity because its PPO activity is only 20-30% that of other Sultana clones although it contains similar levels of phenolic compounds (Rathjen & Robinson, 1992).

Selection of rootstock can influence PPO activity in fresh fruit of Sultana with the highest activity seen in grapes grafted to Dogridge and least in those grafted to 110 Richter (Jogaiah et al., 2014).

Figure 1: Adsorption isotherm (- - -) and effect of water activity on total (●), enzymatic (♦), and non-enzymatic browning (▲) of Sultana (50 °C); adapted from Aguilera et al. (1987).



4.2 Non-enzymatic browning - Maillard reaction

The Maillard reaction is a chemical reaction between free amino groups usually of an amino acid or protein and carbonyl groups of reducing sugars such as glucose and fructose. The reaction does not require the presence of a specific enzyme and can lead to the formation of dark pigments.

In grapes Maillard reactions are often associated with relatively high temperatures and intermediate moisture but may also proceed at ambient temperatures although at slower rates (Spanos & Wrolstad, 1990). Berry temperatures above 60 °C are observed when untreated fruit is dried naturally in direct sunlight on the vineyard floor as commonly practiced in California (Christensen & Peacock, 2000). Such fruit has a dark colour and a malty caramel like flavour which has been associated with non-enzymatic browning reactions (Ramshaw & Hardy, 1969).

There is little direct evidence of significant non-enzymatic browning while emulsion treated fruit is still drying on the trellis or on racks. However, during storage of dried fruit significant browning may result from non-enzymatic Maillard reactions (Frank, 1998; Frank et al., 2004a,b, 2005). Major contributing factors are the temperature and moisture content of the fruit and the oxygen content of the atmosphere around the fruit. Agronomic management decisions in the vineyard are also important in that they may predispose the susceptibility of dried grapes to non-enzymatic browning during storage. Important fruit attributes in that context are fruit maturity (see section 6.1 on page 10), vine nitrogen status (see section 6.3 on page 6.3) , irrigation level and fruit exposure to sunlight.

5 Drying principles

The physical and chemical structure of the berry surface is naturally resistant to water loss. Its outer skin, the berry cuticle, consists of a layer of overlapping wax platelets or bloom. (Radler, 1965a). Their arrangement together with the chemical composition of the cuticle makes the skin resistant to water loss as water vapour. The drying emulsion employed in grape drying disrupts this arrangement and thus accelerates berry dehydration.

5.1 Emulsion related issues

The grape drying industry in Australia adopted the Turkish method of drying in the early 1920s (Penman & Oldham, 1954; Grncarevic & Lewis, 1976). It consisted of dipping fresh fruit into an emulsion of olive oil in a potassium carbonate (K_2CO_3) solution at ambient temperature. The method produces light golden fruit, a fact that strongly contributed to its adoption. In the 1940s olive oil was replaced by alternative, commercially available dipping oils. A subsequent systematic evaluation of the drying process demonstrated that the drying rate of grape berries depends largely on the components of a soft wax that forms part of the cuticle and cannot be removed separately (Martin & Stott, 1957; Radler, 1964, 1965a,b). Application of a drying emulsion thus facilitates the passage of water through the berry cuticle leading to a three fold increase in the drying rate.

5.1.1 Emulsion composition and strength

The original dip drying method recommended a solution strength of 2.5% potash (K_2CO_3) without providing a specific volume of oil to be added to the emulsion but it probably ranged between 1 – 2% of a commercially available drying oil (Penman & Oldham, 1954) (Table 2).

A similar solution strength of 2.5% potash and 1.5 – 2.0% oil was later recommended for rack drying which by the late 1970s had largely replaced dip drying. Better emulsion cover was obtained by splitting the rack application into an initial spray of 2/3 normal strength at the normal volume followed by a spray of 1/3 strength at a lower volume after no later than four days (Grncarevic & Lewis, 1976). However, respraying the rack with a second application was also found to raise the level of soft textured “puggy fruit” which is more prone to damage during processing (Clingeleffer, 1996b).

Modern day drying emulsions are still composed of a water based K_2CO_3 solution of up to 2.5% and contain a commercial oil of up to 2% (v/v) with a pH ranging between 9.5 and 11.5. The oils consist of a mixture of ethyl esters of fatty acids of lengths $C_{14}/C_{16}/C_{18}$. The composition of salt (K_2CO_3) and drying oil are believed to exert an additive or synergistic effect on the drying process

Table 2: Recommendations of emulsion strength, composition and application timing.

Application method	Timing	Oil	Potash	Source
		%		
Dip		-.-	2.5	Penman & Oldham (1954)
Rack spray	Initial	1.00 – 1.33	1.67	Grncarevic & Lewis (1976)
	Second	0.50 – 0.67	0.83	
Rack spray	Initial	1.00	1.25	Clingeleffer (1993a,b, 1996a)
	Second	0.50	0.60	
Vine spray	Initial	0.50	0.60	Clingeleffer (1993a,b, 1996a)
	Second	0.50	0.60	

and commercial formulations currently in use have been shown to be most effective relative to emulsions with alternative salts and oil compositions (Grncarevic, 1963; Uhlig & Walker, 1996; Uhlig et al., 1996).

During the late 1980s and early 1990s, the recommended strengths of the drying solutions for rack drying was considerably reduced to around half the original strength (Clingeleffer, 1993a,b, 1996a). It was suggested that half strength drying emulsions of 1.0% oil and 1.25% potassium carbonate applied for rack spraying gave the highest quality fruit. Experiments had demonstrated that there was no advantage in exceeding that strength in order to attain a faster drying rate and thus reach the desired moisture sooner (Table 2).

For trellis drying it was recommended to again halve the application rate to 0.5% oil and 0.6% potash (Table 2) after field experiments had shown that it achieved light amber/yellow fruit (Clingeleffer, 1993a,b, 1996b). It was argued that a more concentrated emulsion is likely to lead to excessive levels of berry damage during processing, often resulting in sticky fruit due to excessive moisture uptake during processing. High emulsion levels were found to enhance the initial drying rate but had little effect at later drying stages.

5.1.2 Emulsion volume

The difficulty in determining an appropriate application volume at a given strength results from the challenge of being able to effectively deliver sufficient emulsion to each berry within a bunch.

May et al. (1983) reported that comparable amounts of a standard full strength emulsion are more effective when spotted uniformly to single berries instead of concentrated toward the tip on the berry surface. Drying accelerated as berries received more spots of emulsion. Approximately 9 μl of emulsion placed by spotting or part-immersion gave raisins of similar quality to raisins dried after total immersion, despite slower drying rates during the first 36-48 h of dehydration. Any further reduction in the amount of emulsion led to slower drying and darker raisins. A volume of 9 μl per berry is equivalent to 6.1 l tonne^{-1} of fruit or 139 l ha^{-1} (Table 3).

Spraying single berries instead of spotting achieved a maximum drying rate with only 1.5 μl of emulsion per berry, less than a tenth of the volume of emulsion that normally adheres to a berry after full immersion when dip drying (Table 3). The volume is equivalent to around 1 l tonne^{-1} of fresh fruit, or 23 l ha^{-1} and corresponds to just under 4% of the volume recommended for commercial rack drying (Table 3). Spray volumes for rack drying seem excessive relative to those achieved by spraying single berries but apparently are necessary in order to wet the inaccessible berries inside dense bunches. Insufficiently wet berries can lead to the presence

Table 3: Emulsion volume per berry, per tonne of fresh fruit and per hectare as a function of application method (May et al., 1983). Drying oil volumes (2.0% V/V) and weight of potash (2.5% W/V) applied per hectare in a full strength emulsion are also included. Calculations are based on a yield of 22.6 tonnes of fresh fruit ha^{-1}.

Target	Application	Emulsion			Oil	Potash
	method	μl berry^{-1}	l tonne^{-1}	l ha^{-1}	l ha^{-1}	kg ha^{-1}
Berry	Dip	37.0	25.0	565	11.3	14.1
	Spotting	9.0	6.1	139	2.8	3.5
	Spray	1.5	1.0	23	0.5	0.6
Fruit	Dip		27.0	610	12.2	15.3
	Rack		56.2	1276	25.5	31.9
	Trellis		300.0	6780	135.6	169.5

of incompletely dried grapes or “blobs” (Grncarevic & Lewis, 1976; Clingeleffer et al., 1980). Blobs increase the number of dark berries and thus lower fruit quality. They also increase the cost of processing.

Even larger volumes, around ten times those recommended for rack drying, are applied for the commercial production of trellis dried fruit (Table 3). Up to two thirds of the emulsion applied misses the target or is intercepted by the vine leaf canopy before reaching the bunches. High volumes are applied with the objective to ensure that all fruit, including berries inside dense bunches, are covered with sufficient emulsion. Current recommendations have reduced the emulsion strength for trellis drying by half after field trials had indicated there was no detrimental effect on drying rate and fruit quality (Clingeleffer, 1993a,b, 1996b).

5.1.3 Emulsion effectiveness - spray penetration

The challenge in achieving rapid drying rates for trellis drying is the effective delivery of sufficient drying emulsion to each bunch and, more importantly, to every berry within each bunch. In rack drying good berry coverage is achieved by repeated spraying rather than by increasing the concentration (Grncarevic & Lewis, 1976; Clingeleffer et al., 1980; Clingeleffer, 1993b). A second application might be of similar benefit in trellis drying to reach berries that initially did not receive sufficient emulsion. However in practice this seems to be rarely the case unless it rained after the first application. It is not entirely clear why, but is possibly due to additional cost of a second application.

Spraying large volumes of emulsion onto trellised fruit is costly and consequently early research was looking for methods that would require lower volumes of emulsion (Clingeleffer et al., 1977). A specifically designed “starwheel” spray unit was developed, capable of delivering the emulsion close to the bunches to ensure good fruit coverage without having to apply excessive spray volumes. A minimum volume of 4000 l ha^{-1} of a full or at least three quarter strength drying emulsion was sufficient to trellis dry Sultana. The technique effectively halved the normally required spray volume. However despite the fact that it had achieved its stated objective the “starwheel” concept was never taken up by industry and was never applied in practice.

Instead, the industry adopted the use of conventional spray units capable of applying volumes in excess of 7000 - 8000 l ha^{-1} and equipped to capture and reuse run-off emulsion (Dried Fruits Australia, 2008).

There is recent evidence to suggest that emulsion volumes may be reduced to as low as 4,000 l ha^{-1}, similar to those achieved with the "starwheel" concept (Clingeleffer et al., 1977) and equivalent to just above half the recommended volume (Mollah, 2006a,b). Reduced volumes were applied without affecting the coverage of berries inside tight bunches and without any negative effects on fruit colour grading and moisture content. They demonstrated that reduced volumes may be achieved by driving a standard wetting machine faster (4 km h^{-1}) and using smaller size nozzles spraying double strength emulsion. Potential use of simple and cheap wetting machines without the capacity for recycling emulsion was seen as an added benefit.

Current emulsion compositions are optimal and applied volumes are adequate. The volumes applied for trellis drying are high but are used to ensure good coverage inside dense bunches and clumps of dense bunches on the trellis. Factors associated with optimal emulsion delivery should be re-evaluated.

5.1.4 Emulsion effectiveness - super wetters and adjuvants

The effectiveness of the drying process may be enhanced by adding synthetic oil or water soluble "super wetters" or adjuvants to the drying emulsion. The addition of *alkyl silicone* based adjuvants or water soluble *organosilicones* reduces the surface tension of the drying oil and thus enhances its spread across the grape surface and toward the interior berries of single bunches (Mollah, 2006b).

Under adverse weather conditions the addition to the drying emulsion of "Breakthru™ TurboDry" (TD), an oil soluble alkyl silicone, led to shorter drying times and better fruit quality but not under ideal drying conditions, when fruit treated with additional TD was of similar quality to fruit under standard practice without TD (MacGregor & Gaskin, 2005; Mollah, 2006b).

Adding a water soluble organosilicone "s240" to the drying emulsion, either alone or in combination with TD, gave inconclusive results (Mollah, 2006b). In general the loss of moisture from grape berries within the first 10 days after spraying was accelerated by the use of double strength emulsion containing TD or s240. However, the initial acceleration did not carry through to harvest and did not result in dried grapes of better colour grading. The use of adjuvants did not affect emulsion cover of berries inside tight bunches and this may partly explain the relatively short term effect of the treatment.

In general, the effect of silicone based wetters appears to be restricted to the initial stages of drying and ultimate benefits to fruit quality are most likely restricted to unfavourable drying conditions.

This limited benefit is possibly related to the initial drying conditions inside tight bunches. Good coverage and spread of emulsion over interior berries does not necessarily and immediately lead to an accelerated drying rate relative to external berries. Initially, after spraying, the relative humidity inside dense bunches is probably close to saturation because of little or no airflow that would allow the humid air to escape. Drying rate is driven by the difference in vapour pressure between the berry and the surrounding atmosphere and therefore is slow until gaps develop that allow humid air to escape and be replaced by dry air able to absorb more moisture from the wet berries. Any improvement in air flow around and between bunches is therefore most likely to accelerate the early drying phase. For example, the prompt removal of leaves from the fruiting zone prior to spraying is likely to enhance air flow around bunches and will also maximise interception of emulsion by the bunches rather than other vine organs. The emulsion spray should be strictly targeted to the bunch zone by using appropriate jet and nozzle configurations.

5.1.5 Antioxidants – metabisulfite

Sodium metabisulfite is an antioxidant used to prevent browning in many fruit products. It has been applied to mitigate the effects of rain damage due to berry splitting (Hayes & Welsh, 1997). Applying it to rack dried fruit, subsequent to the drying emulsion, improved colour rating and reduced surface sugar on the berries. Applying metabisulfite on the vine before harvest and before applying the drying emulsion did not improve colour rating relative to untreated vines.

Metabisulfite addition to the drying emulsion, or applied by spraying 3 days later on the rack produced lighter, redder and less yellow Sultanas but increased damage index and compaction. It was concluded that unless major benefits from mould control can be demonstrated its use by industry should be avoided (Tarr & Clingeleffer, 2000).

There is little or no information on the use of antioxidants like sulfur or metabisulfite when applied at the time of cane cutting for trellis drying. Potential benefits may result from the prevention of enzymatic and non enzymatic browning if wettable sulfur, sulfur dust or metabisulfite were applied with or shortly after the drying emulsion.

6 Agronomic factors

6.1 Maturity of the berries

In Sultana and Merbein Seedless grapes there is an optimum maturity range between 22 and 23°Brix when berries are most likely to develop the most desirable golden yellow color (May et al., 1983; Uhlig & Clingeleffer, 1998a). Immature berries tend to dry with a darker colour except for berries without emulsion which also brown when mature. Emulsion spreads more effectively on mature berries and the degree of spread follows a linear relationship with maturity (May et al., 1983).

Beyond a threshold of 23°Brix the relationship becomes negative such that berries of higher °Brix tend to dry darker (Uhlig & Clingeleffer, 1998b; Uhlig, 1998). The increasing proportion of dark fruit of maturities beyond 23°Brix has been attributed to rising levels of non-enzymatic browning while that of immature berries below 22°Brix is attributable to the action of PPO because of a prolonged drying time.

It is interesting to note in this context that at any given date between veraison and harvest the maturity of single berries may vary within a range of 8.3°Brix (Uhlig, 1998). This means that a considerable proportion of berries, even at the optimum level of 22–23°Brix would still be at maturities likely to brown easily. The impact seems to be more severe at a lower average maturity because the rate of change of the relationship between °Brix and lightness increases as it approaches the optimal range of 22–23°Brix.

Much of the variance in maturity is often determined early in the growth cycle because of uneven bud burst and may be due to cold weather events, insufficient irrigation during winter or insufficient vine reserves.

Maturity also influences fruit processing and storage characteristics such that higher sugar levels are associated with lower skin damage during harvest and handling, while immature fruit with high acidity is strongly linked to greener fruit before processing which goes brown and dark during storage (Tarr & Clingeleffer, 2000).

Maturity and importantly its variability between single berries is a most crucial factor in achieving uniformly light coloured fruit. Maturity varies strongly across or between vineyards and between seasons due to variations in climate, soil type and management inputs like irrigation *and fertiliser. Maturity should therefore be monitored closely to avoid processing of immature, green fruit of high acidity.*

6.2 Vine spacing

Wider inter-vine spacing has been advocated as a method to reduce vine vigour (Krstic, 2004) and to potentially support a more even fruitfulness from season to season in varieties like Sultana, particularly when grafted to the rootstock Ramsey. An inter-vine spacing of 4.8 m relative to 3.6 and 2.4 m successfully reduced shoot vigour of Sultana while production was maintained at similar levels relative to narrower spacing and spacing had no influence on fruit colour gradings (Krstic, 2004; Krstic & Hancock, 2007).

Intuitively, a reduction in vigour should have beneficial outcomes for both bunch distribution and structure through a reduction in bunch density and berry size and both should improve emulsion cover and drying rate. Reduced vigour may result in a less dense foliage cover with improved ventilation and air flow for drying.

6.3 Plant nutrition - nitrogen

Nitrogen supply is an important factor in achieving high productivity in dried fruit production. A lack of plant available nitrogen has the potential to significantly limit yield of Sultana. Conversely, an oversupply can lead to excessive vigour which in turn may have detrimental impacts on vine microclimate, fruitfulness and productivity. (Treeby, 2001; Sommer et al., 2000, 2001). Vine nitrogen supply is often mirrored in the berries at harvest in their content of various nitrogenous substances like amino acids (Kliewer, 1970, 1971).

The level of amino acids in the berry at harvest has been linked with the tendency of dried Sultana toward non-enzymatic browning during storage (Frank, 1998; Frank et al., 2004a). Furthermore, although there is no direct evidence, it is possible that similar processes of non-enzymatic browning occur on the vine during trellis drying as long as the required substrates are present and the environmental conditions are favourable (Frank et al., 2004b, 2005).

Limiting berry nitrogen supply is likely a promising strategy to reduce the tendency toward non-enzymatic browning but requires close monitoring of vine nitrogen status during key growth stages and appropriate management of nitrogen fertigation (Holzapfel & Treeby, 2007; Treeby, 2013).

Conversely, a shortage in berry nitrogen supply may indirectly promote the formation of substances conducive to enzymatic browning (Treeby, 2013). The amino acid phenylalanine and its metabolites are an important substrate for phenolic and flavonoid substances involved in enzymatic browning and tend to accumulate in berries when nitrogen is in short supply (Olsen et al., 2009).

A strategy to reduce berry nitrogen supply may be beneficial for the prevention of non-enzymatic browning during storage but at the same time may promote enzymatic browning during the drying process on the vine or rack.

6.4 Canopy management

Canopy management is the manipulation of shoots, leaves, and fruit toward optimum yield and fruit quality. The canopy describes the leaf and shoot system of the vine and plays a crucial role in light energy capture, water use and microclimate of ripening grapes. Canopy management includes practices like pruning, shoot trimming, shoot or cane positioning and vine training (Smart, 1992). In dried fruit production practices generally aim towards maximising yield while maintaining healthy grapes and vines.

6.4.1 Trellis design

Trellis design for dried fruit production has undergone significant changes over the past 30 years. There has been a steady shift away from low (1 m) narrow trellises, using mostly Sultana on own roots, to tall trellises (1.5 to 2 m) with hanging canes and a predominant use of grafted vines with relatively high vigour and large canopy surfaces.

Evolution of modern trellis designs has been mostly driven by the desire to mechanise all stages of production. Key developments include a movable swing-arm trellis instead of a fixed trellis, such that the non-fruiting replacement shoots and the fruit bearing canes are positioned in separate zones. Canes thus may be cut mechanically and the drying emulsion targeted effectively towards the fruit zone. (Clingeleffer, 1998, 2002).

Advances in trellis design and the adoption of vigorous rootstocks have contributed to a steady increase in vine productivity (Clingeleffer, 2002). Vines on modern trellises, because of their larger canopy envelope, have a greater capacity to capture and use sunlight than the shorter and narrower trellises used in the past (Sommer et al., 2000; Sommer & Islam, 2000). Excessive canopy growth may however lead to shading of replacement canes and thus compromise fruitfulness (see section 3.2.1 on page 3). Dense canopies also have a tendency to inhibit air circulation and thus retain high levels of relative humidity which may favour fungal growth particularly after periods of rain.

Excessive canopy vigour may also delay ripening or lead to uneven ripening and drying with negative consequences for fruit colour (see section 6.1 on page 10). For example, berries that developed on the external portion of the canopy were smaller and dried faster than those from internal more shaded parts (Muganu et al., 2011).

Dense leaf canopies with long shoots that touch the vineyard floor are likely to impede air flow between vine rows and thus contribute to a microclimate favourable to fungal infection. Currently such effects are not well documented for dried fruit production.

Ideally vine vigour should be balanced such that shoot and leaf coverage is sufficient to prevent sunburn of fruit but sparse enough to allow adequate light penetration and canopy ventilation. Appropriate parameters have been documented for wine grape production but are not directly applicable for dried fruit production (Dokoozlian & Kliewer, 1995a,b).

6.4.2 Number of bearers

The inherently variable fruitfulness of Sultana has been documented and investigated over many years (Antcliff & Webster, 1955; Antcliff et al., 1955; Sommer et al., 2000, 2001; Treeby, 2001). A sufficiently high fruiting potential is best achieved by maximising the number of bearing shoots and bunches per vine with the added benefit of reducing the average bunch volume and berry size. Both variables are beneficial in achieving good emulsion coverage and drying rates which in turn are likely to reduce the potential for browning.

6.4.3 Leaf removal

Many producers who have adopted trellis drying mechanically strip the leaves from fruit bearing canes immediately before cutting. The operation aims to facilitate spray penetration and coverage of the bunches with drying emulsion. However, there is little documented information if this operation improves emulsion coverage and drying rate and possibly reduces emulsion volumes.

Leaf removal did lead to faster drying rates than in a full canopy probably due to improved air circulation (Schache et al., 1993). However, leaf removal also resulted in the re-absorption of moisture by the bunches after light rain while bunches on a full canopy were protected. It is however doubtful if a full canopy would give similar protection during heavy rain. Fruit on north facing canopies dried faster than fruit facing south but differences in drying rate were small such that the drier fruit facing north was around 1 day behind fruit facing south.

In cool climate wine grape production leaf removal is often practiced to increase exposure of fruit to direct sun with the aim to enhance berry flavour and colour development (Smart et al., 1990). In dried fruit production such practices would probably lead to darker drying fruit (Uhlig, 1998) but fruit might dry faster and be more resistant to processing damage because exposed berries are often smaller and have thicker skin (Muganu et al., 2011; Clingeleffer et al., 2003).

Leaf removal prior to cutting the canes for drying will most likely increase the air flow around the drying bunches and thus reduce humidity while improving direct absorption of radiant sunlight by bunches. There is a lack of documented information on the effect of leaf stripping on emulsion coverage and drying rate.

6.4.4 GA (gibberellic acid) application

In dried fruit production GA has been used to loosen the bunch structure of Sultana with the aim to improve spray penetration and air flow around the bunch and thus improve drying rate. Pre-flowering GA applications did promote stem elongation during the early stages of berry development but the effect did not persist until harvest and therefore did not sufficiently “loosen” bunches for better spray penetration (Schache et al., 1993). GA applications did increase berry size.

A single post-set application of GA has been shown to reduce berry splitting caused by rain at, or just prior to harvest (Clingeleffer et al., 2003). The installation of plastic vine covers prior to harvest also reduced splitting relative to uncovered vines. Presumably both techniques could be used to minimise losses from rain damage and subsequent mould development. However it was found that GA increased berry size, altered the shape, size and number of skin cells and increased processing damage (Clingeleffer et al., 2003).

6.4.5 Vineyard floor management

Floor management in dried fruit production ranges from complete cultivation to complete non-tillage and from maintaining a cover crop throughout all or part of the season to no cover crop at all (Hirschfelt, 2000). The choice of a suitable management is strongly determined by factors like soil type, irrigation system, available machinery and others including the personal preference of the operator.

Floor management using temporary or permanent cover crops may greatly improve soil health by adding and maintaining soil organic matter with improved infiltration and trafficability of the vineyard (Tesic et al., 2007). Conversely, cover crops compete with the vine for water and nutrients and therefore may reduce productivity (Steenwerth & Belina, 2008).

Floor management practices suitable for mechanised dried fruit production must facilitate the trellis drying operation. It should therefore include the total elimination of weeds and cover crops well before cutting the canes for drying. An actively growing cover crop transpires water and thus contributes to the prevailing relative humidity in the vineyard. In addition, depending on its height it will impede air flow and reduce the drying potential around the bunches. A clean and dry vineyard floor on the other hand is likely to reflect radiation into vineyard canopy and will facilitate the heating and drying of bunches. No documented information was found regarding the direct effect of floor management and its effect on drying conditions immediately before and during trellis drying.

6.5 Irrigation management

6.5.1 Irrigation type

Drip irrigation is increasingly becoming the dominant irrigation type in wine grape and to a lesser extent in dried fruit production, where full cover low level sprinklers are still widely used. There is only a small proportion of overhead and furrow irrigation in dried fruit production (Argus & MacGregor, 2014).

Full cover irrigation is often used for the purpose of evaporative cooling on very hot days and has the potential to reduce vineyard temperature by several degrees. Full cover irrigation therefore significantly contributes to the relative humidity in the vineyard particularly while the soil is wet. It is therefore desirable to cease irrigation shortly before or immediately after canes have been cut to accelerate drying.

6.5.2 Water stress

Water stress during drought or imposed by deficit irrigation has the potential to strongly affect growth and production of dried fruit varieties like Sultana and Sunmuscat (Sommer, 2011; Sommer et al., 2012). Short term stress reduces transpiration and assimilation rate but normally does not impact yield, while ongoing deficits may lead to a significant reduction in vegetative growth, bearer number and productivity.

Water deficits can result in an increased production of flavonoids in wine grapes (Esteban et al., 2001). There is however little evidence that this is the case in the dried grape varieties Sultana or Sunmuscat where fruit colour score of strongly water deficient vines was similar to those of well watered control vines (Sommer, 2011). Increased colour formation in water deficient vines may be due to an indirect effect of bunch light exposure because water deficits are often associated with reduced shoot and leaf growth. Alternatively, flavonols and other phenolics in water deficient vines are simply more concentrated because their berries are smaller than those of well watered vines.

Grape vines are quite resilient to water deficits and mild transient water deficits have little or no impact on performance and yield (Sommer, 2011; Sommer et al., 2012). Over-irrigation on the other hand, particularly in combination with high rates of nitrogen fertilizer, can lead to excessive vine vigour and dense leaf canopies with negative implications on grape maturation (Kliewer & Ough, 1970), berry skin resistance (Clingeleffer et al., 2003) canopy microclimate and drying conditions, all negative factors in the context of browning.

7 Rootstock and variety selection

7.1 Rootstock selection

A relatively small number of rootstock varieties is being used in dried grape production in Australia with Ramsey being the most dominant for Sultana production and 1103 Paulsen for Sunmuscat.

Alternative rootstock varieties have been evaluated for their potential use in dried fruit production (Fletcher, 2001; Downey et al., 2008). The work suggests that the choice of rootstock has a consistent impact on dried fruit quality and colour grading of H4 Sultana. Lider 187-24 and Paulsen consistently produced higher quality fruit grades than seven other scion rootstock combinations (Table 4). The worst combination was Sultana H4 grafted to Schwarzmann, closely followed by Ramsey, Kober and Ruggeri, which were equally poor performers.

Table 4: Propensity of Sultana H4 to produce fruit of light colour and high yield when grafted to 9 different rootstocks (Downey et al., 2008).

Rootstock	Light colour	Yield
101-14 Millardet	+	−
1103 Paulsen	++	++
140 Ruggeri	−	+
5BB Kober	−	−
Lider 187-24	++	++
Lider 116-60	+	+
Ramsey	−	++
Schwarzmann	−−	−
Sultana	−	−

Ramsey grafted vines have a tendency to produce green, fragile, more compacted fruit relative to Sultana on own roots, particularly when managed on small trellises with excessive shading (Tarr & Clingeleffer, 2000). Sultana on Ramsey tends to have larger berries with thinner skins relative to Sultana on own roots (Clingeleffer et al., 2003). Conversely, when grown on a tall open Shaw trellis and when vigour is controlled by limiting irrigation, such negative attributes are largely avoided, although fruit still tends to be more fragile with higher levels of processing damage and moisture uptake during storage (Tarr & Clingeleffer, 2000). Sultana on 1103 Paulsen tends to produce light fruit of better quality than on Ramsey (Tarr & Clingeleffer, 2000).

Other grape attributes with the potential to influence dried fruit quality of Sultana (Thompson Seedless) are total proteins, reducing sugars, phenol contents, and PPO activity in both fresh grapes and raisins. PPO activity was highest in grapes grafted on ‘Dogridge’, while it was least in 110 R (Jogaiah et al., 2014).

Desirable attributes like tolerance to salinity, nematodes and drought have made Ramsey the dominant rootstock in dried fruit production. However, attributes associated with light coloured fruit, such as low bunch density and berry size, high skin strength, early maturity and low vigour tend to be negatively affected on Ramsey grafted relative to own rooted Sultana or compared with other rootstocks. Sultana on alternative rootstocks like Lider 187-24 or 1103 Paulsen is likely to produce lighter fruit than on Ramsey (Downey et al., 2008).

7.2 Variety selection

Over the last ten to fifteen years there has been a shift toward varieties other than Sultana because of its susceptibility to rain damage and mold during the harvest period and the tendency to produce dark fruit.

The variety Sunmuscat is now grown widely. It is more rain tolerant than Sultana and has large open bunches that are easily penetrated by emulsion sprays.

Merbein Seedless has long been considered as an alternative variety to Sultana but has been shown to have higher levels of processing damage due to the development of larger berries and differences in the thickness of the surface waxes, the cuticle layers and the shape and size of skin cells (Clingeleffer et al., 2003).

Alternative varieties with low browning potential are also being developed by conventional breeding and genetic transformation (Clingeleffer et al., 2006, 2007; Clingeleffer & Tarr, 2007; Clingeleffer, 2009).

7.2.1 Conventional breeding

The low browning, Bruce's Sport Sultana clone is being made available for planting. It offers potential to reduce the risks of fruit darkening due to rain events during the later stages of drying if grafted on high vigour Ramsey rootstock and managed on a swing-arm trellis (Clingeleffer, 2009).

Early ripening and rapid drying Californian bred varieties Diamond Muscat, Summer Muscat, DOVine and Selma Pete (Fidelibus et al., 2008) have been evaluated and show promise for planting (Clingeleffer, 2009). It is important that these varieties undergo rigorous evaluation locally, because Californian bred varieties haven't been selected for rain tolerance due to a near total lack of rain during their drying season.

Equal probability of rain throughout the drying months in Australia makes it desirable to plant and develop additional rain-fast varieties. Early maturing varieties take advantage of superior drying rates and therefore greatly reduce the probability of rain damage and the likelihood of browning.

7.2.2 Genetic transformation

Genetic transformation techniques may be employed to directly target the genetic control of the PPO enzyme that causes browning in Sultana (Clingeleffer & Tarr, 2007). It is feasible to down-regulating the PPO gene expression to decrease browning in Sultanas and to successfully produce a number of independent transgenic Sultana lines with consistent low browning potential.

8 On farm storage

On farm storage conditions after harvest are critical to maintain fruit quality during subsequent processing and storage. Ideally fruit should be stored in sealed bulk bins or under controlled atmosphere conditions prior to processing (ie. 55% RH to maintain 13% moisture) to avoid fruit darkening and sugaring (Tarr & Clingeleffer, 1992).

Bulk bin storage of high moisture fruit prior to dehydration (>16%) should be avoided because of the potential for darkening and sugar extrusion leading to sticky fruit which is difficult to process. Even fruit with moderately high moisture content (approx. 14%) is likely to suffer from K^+ extrusion which is associated with high levels of processing damage and compaction (Tarr & Clingeleffer, 2000).

Excessively dry fruit (< 11.5%) is also prone to processing damage and subsequent loss of quality in storage. Ideally fruit stored on farm should be maintained at moisture contents in the range of 12.5-13% (Tarr & Clingeleffer, 2000).

Fruit should be stored in sealed containers at a moisture content between 12 and 13%. Storage of even moderately moist fruit should be avoided to prevent sugar extrusion which may lead to "puggy" fruit prone to rapid browning in storage after processing.

9 Conclusions and recommendations

Climate

- Significant rain during drying is probably the single most detrimental factor in achieving mature trellis dried fruit of light colour. Short and medium term weather forecasts are essential for planning and deciding crucial operations around trellis drying and should be used in conjunction with maturity monitoring to predict drying progress and anticipated harvest dates.

Emulsion

- Current emulsion composition is near optimal and applied volumes are adequate. Applied volumes for trellis drying are high but are used to ensure good coverage inside dense bunches and clumps of bunches on the trellis.
- Factors associated with optimal emulsion delivery should be re-valuated. They include precise targeting of sprays through manifolds, including nozzle sizes, pressure and drive speed.
- The effect of silicone based wetters appears to be restricted to the initial stages of drying and benefits to fruit quality are most likely restricted to unfavourable drying conditions. It would be useful to re-evaluate their effectiveness in preventing dark fruit.
- There is little or no information on the use of antioxidants like sulfur or metabisulfite when applied at the time of cane cutting for trellis drying. Potential benefits may result from the prevention of enzymatic and non-enzymatic browning if wettable sulfur, sulfur dust or metabisulfite were applied with or shortly after the drying emulsion.
- The documented work on emulsion composition and rates historically has focused exclusively on Sultana. The drying of alternative varieties like Sunmuscat may therefore benefit from a re-evaluation of currently recommended emulsion compositions and rates.

Maturity

- Average maturity and the variance of the maturity of single berries is the most crucial factor in achieving uniformly light coloured fruit. Maturity also varies strongly across or between vineyards and between seasons. Measures with potential to accelerate maturity and uniformity of bud burst and flowering should be considered for evaluation. These include use of chemical sprays of hydrogen cyanamide (CN_2H_2) to synchronise bud burst.
- Maturity should be monitored closely to avoid processing of immature, green fruit of high acidity.

Canopy management

- Vine spacing and trellis configuration have an impact on the potential for air circulation within and between vine rows. Tall trellises with open canopies facilitate air flow under the vines and between vine rows. Regular skirting of the leaf canopy will further assist air flow between vine rows.
- Increased vine spacing reduces vigour with potential benefits for bunch distribution and structure through a reduction in bunch density and berry size. Both should improve emulsion cover and drying rate. Reduced vigour may result in a less dense foliage cover with improved ventilation and air flow for drying.

- At pruning time shoots should be evenly positioned to avoid potential clumping of bunches that will be difficult to wet.
- Records of the temperature profile of trellis drying berries in various positions on the vine as well as inside and outside bunches would be useful to assess positional effects within the trellis as well as trellis orientation, and to quantify the effect of management interventions like leaf stripping and vineyard floor management. They would allow quantifying the drying progress in relation to general weather records which in turn might be useful in predicting drying progress.
- Leaf removal prior to cutting the canes for drying will increase the air flow around the drying bunches and thus reduce humidity while improving direct absorption of radiant sunlight by bunches. Impact of leaf removal on drying rate and canopy microclimate should be quantified.
- Ideally, vine vigour should be balanced such that shoot and leaf coverage is sufficient to prevent sunburn of fruit but sparse enough to allow adequate light penetration and canopy ventilation. Appropriate canopy parameters similar to wine grape production should be determined.

Floor management

- Floor management practices suitable for mechanised dried fruit production must facilitate the trellis drying operation. It should therefore include the total elimination of weeds and cover crops well before cutting the canes for drying. A clean and dry vineyard floor is likely to reflect radiation into vineyard canopy and will facilitate the heating and drying of bunches.
- Effects of vineyard floor management, including reflective covers, on the bunch and berry temperatures and drying rate should be evaluated.

Nitrogen

- A strategy to reduce berry nitrogen supply has potential benefits for the prevention of non-enzymatic browning during storage but at the same time may promote enzymatic browning during the drying process on the vine or rack.

Irrigation

- Irrigation should cease shortly before or immediately after canes have been cut to accelerate drying and vines should not be irrigated during the drying period particularly with overhead or low level sprinklers with complete ground cover. If the vineyard is equipped with drip emitters vines may be irrigated during the drying period.

Roostocks

- The relatively limited fruitfulness and high vigour of Ramsey grafted Sultana contribute to the production of large, dense bunches with big berries which are difficult to cover and penetrate with drying emulsion and are likely to dry slowly.
- Sultana on alternative rootstocks like Lider 187-24 or 1103 Paulsen is likely to produce lighter coloured fruit than on Ramsey. Lider 187-24 should be readily available to industry.

Varieties

- Equal probability of rain throughout the drying months in Australia makes it desirable to plant and develop additional rain-fast and early-maturing varieties.

On farm storage

- Fruit should be stored in sealed containers at a moisture content between 12 and 13%. Storage of even moderately moist fruit should be avoided to prevent sugar extrusion which may lead to “puggy” fruit prone to rapid browning in storage after processing.

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