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CURRENT TOPICS

Variations in phytosanitary and other management practices in Australian grapevine nurseries

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Summary. Sporadic and costly failure of newly planted vines is an ongoing problem in the Australian wine industry. Failed vines are frequently infected with wood pathogens, including the fungi associated with Young Vine Decline. Hot water treatment (HWT) and other nursery practices have also been implicated in vine failure. We undertook a survey of Australian grapevine nurseries to develop an understanding of current propagation practices and to facilitate the development of reliable propagation procedures that consistently produce high quality vines. A survey covering all aspects of grapevine propagation including sources of cuttings, HWT, sanitation and cold storage was mailed to all 60 trading Australian vine nurseries. In all, 25 nurseries responded, a response rate of 41.7%. Practices were found to vary widely both within and between nurseries. The vast majority of respondents (20) reported that they currently used, or had used, HWT, but the reliability of HWT was questioned by most nursery operators. A majority (18) felt that some *Vitis vinifera* varieties were more sensitive to HWT than others. Hydration also emerged as an important factor that had the potential to affect vine quality. All respondents used hydration and although the majority used treated water, cuttings were not generally seen as a source of cross contamination. Our study identified a clear need for further research into the effects of HWT on cutting physiology and the role of hydration in the epidemiology of grapevine pathogens, and the importance of incorporating the results of such research into practical and comprehensive propagation guidelines for vine nurseries.

Key words: hot water treatment, black-foot disease, Petri disease, young vine decline, *Vitis vinifera*.

Introduction

Since the Australian wine industry planting boom in the 1990s, the quality of grapevine planting material available in Australia has been variable. Sporadic and costly failures of large batches of vines have been an ongoing problem for both grape growers and nurseries in Australia and overseas (Whiting *et al.*, 2001; Waite and Morton, 2007). Many of the failed vines that were planted during the boom between 1995 and 2005 were found to be infected with endogenous pathogens (Morton, 2000; Edwards *et al*., 2001; Gatica *et al*., 2001; Halleen *et al*., 2003; Fourie and Halleen, 2004b). *Cylindrocarpon* spp. and Botryosphaeriaceae spp., with and without *Phaaeomoniella chlamydospora* and *Phaeoacremonium* spp., are associated with Young Vine Decline (Pascoe and Cottral, 2000; Alaniz *et al*., 2007; Petit *et al*., 2011; Whitelaw-Weckert *et al*., 2012). *P. chlamydospora* and *Phaeoacremonium* spp. alone also cause Petri disease in younger vines (Crous and Gams 2000; Edwards and Pascoe, 2001) and later, in complexes with various basidiomycete pathogens, cause esca in mature vines (Mugnai *et al*., 1999)

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A range of other factors including hot water treatment (HWT), which is commonly used to control endogenous pathogens in dormant cuttings and rooted vines, poor nursery sanitation and cold storage (Caudwell *et al*. 1997) are also implicated in vine failure (Fourie and Halleen, 2006; Waite and Morton, 2007; Gramaje and Armengol, 2011). HWT, the immersion of dormant cuttings in hot water at 54°C for 5 min for short duration HWT, or 50°C for 30 min for long duration HWT in Australia (Waite and Morton, 2007), 50°C for 30 min in South Africa (Crous *et al.*, 2001), 50°C for 45 min in France (Caudwell *et al.*, 1997), 53°C for 30 min in Spain (Gramaje *et al*., 2009a) and 47°C in New Zealand (Graham, 2007), is widely accepted to be important for the production of high quality planting material (Fourie and Halleen, 2004b; Gramaje *et al*., 2009a) and was adopted in Australia to prevent the transmission of endogenous diseases in planting material following the emergence and identification of the phytoplasma disease, Australian Grapevine Yellows (AGY) in the early 1990's (Smart *et al.*, 1995; Wilson & Hayes, 1996), and the identification of *P. chlamydospora* in mother vines used for propagation (Edwards and Pascoe, 2004). HWT is also an effective control for phylloxera (Stonerod and Strik, 1996) and as such satisfies the requirements of the National Phylloxera Management Protocols (National vine Health Steering Committee, 2002) and thus the quarantine regulations for the movement of cuttings and rooted vines between Australian states. However, the transfer of HWT from small batch research laboratory treatments to commercial practice has met with mixed success and significant losses have been attributed to HWT (Waite and Morton, 2007). Concerns expressed by nurseries and growers resulted in a significant body of research into the effects of HWT on cuttings and rootlings (Waite, 1998; Crocker *et al*., 1999; Crocker *et al*., 2002; Waite and May, 2005; Gramaje *et al*., 2009a). Considerable progress was made and protocols were improved and refined (Waite and Morton, 2007), but the effects of HWT and surrounding nursery practices on cuttings and rooted vines cannot yet be predicted with certainty. Further research is needed to develop propagation procedures that are reliable and result in the production of high quality vines. To facilitate the planning of relevant and targeted research (Kelley *et al*., 2003), a systematic survey of Australian grapevine nurseries was undertaken to develop an understanding of current practices and identify those likely to have the most impact on the quality of planting material. The survey was also a means of acknowledging the value and importance of industry engagement with the research and its outcomes, a critical factor in the development and adoption of best practice (Black, 2000; Piderit, 2000; Pannell *et al*., 2006).

Materials and methods

Survey type

A mailed paper and pencil survey (Hoyle, 2002) was sent to all 65 identifiable Australian vine nurseries. Telephone interviews, in the first instance, were ruled out as a first approach because of the difficulty of contacting busy nursery operators who work mainly out of doors and are often out of mobile telephone range during the day, and evening calls are perceived negatively. Face to face interviews and nursery visits were impractical because of remote locations and high cost of travel (McHorney *et al*., 1994; Hoyle, 2002). Electronic surveys would have also been difficult to administer as there were no public email addresses for more than half of the nurseries and many of the nursery managers are known to be in the age group (over 50) where familiarity with the internet cannot be automatically assumed.

The relative anonymity of pencil and paper surveys also places some physical and psychological distance between author and participant and elicits a less biased response, as does the identification of a university as the sponsor of the survey (Hoyle, 2002; Pennings *et al*., 2002). A disadvantage shared with other survey types where participation is not compulsory, is the empirical bias resulting from the self selecting nature of the respondents (Kelley *et al*., 2003). Primary producers often complain of a constant flood of bureaucratic and regulatory correspondence that is time consuming, of little perceived benefit and takes them away from essential farming activities. Consequently non essential paperwork is often ignored and surveys frequently go unanswered (Heberlein and Baumgartner, 1978; Pennings *et al.*, 2002; Conelly *et al.*, 2003).

Survey design

The survey consisted of 26 questions divided into two sections; 1) hot water treatment and 2) other nursery practices. Section 1 questioned nursery operators about their use of and opinions about HWT. Section 2 covered the use of hydration (immersion of dormant cuttings and or rooted vines in water), water treatment and general sanitation and cold storage and fungicides, factors that are known to interact with HWT and affect the quality of the vines produced (Waite and Morton, 2007). A draft of the survey was sent to the executive of the Vine Industry Nursery Association for review before final formatting and distribution.

Each section included both closed and open questions and covered all aspects of grapevine propagation. The closed format was used for both factual and subjective questions. Closed questions have a number of benefits including reduction of time taken to complete the survey and standardization of responses, but may not offer all alternative responses (Kalton and Schuman, 1982; Kelley *et al*., 2003). To ensure that vital information was not inadvertently excluded, open questions were linked with some closed questions to provide the opportunity for respondents to elaborate on their replies.

As an incentive to complete the survey, respondents were offered feedback in the form of a summary of the survey results and the opportunity to comment further by participating in more extended telephone interviews following the initial survey (Powers and Alderman, 1982). The surveys were mailed out in autumn 2009, a relatively quiet time in the nursery calendar when operators are more likely to have time to attend to non essential matters.

Results

Initially 20 replies were received and a further five responded after a follow up letter. It became apparent from received phone calls, emails and returned mail, that at least five nurseries had ceased trading, or were no longer growing grapevines, reducing the cohort of extant nurseries from 65 to 60, thus giving a response rate of 42%, a relatively high response rate for primary producers (Hayman and Alston, 1999; Kelley *et al*., 2003). Furthermore, ten respondents agreed to a telephone interview to discuss the survey results and 17 respondents (68% of all respondents) requested a copy of the results indicating a high level of interest and engagement among respondents (Powers and Alderman, 1982).

Statistical analysis

Although the response rate was relatively high (Hayman and Alston, 1999), the low actual numbers of responses (25) and the self selecting nature of the respondents, mean that the capacity to apply statistical tests to the data is very limited and results may be biased, particularly as the capacity to collect demographic information was not available (Kanuk and Berenson, 1975; McHorney *et al*., 1994; Groves, 2006). Therefore, we report proportions and summary statistics only.

Survey Part I - Hot water treatment

The majority of respondents (80%) reported that they currently used, or had used, short and/or long duration HWT (SdHWT and LdHWT). Both on-site and off-site HWT plants were used (56% of respondents each), with 24% of nurseries reporting using both on and off site plants; a consequence of moving material between quarantine jurisdictions, rather than one of insufficient on-site capacity. Eight percent of respondents reported that they did not use HWT at all, but acknowledged using HWT plants in a later question (one on-site and one off-site), thus 88% rather than 80% of respondents had either used, or were currently using, HWT. More respondents (72%) reported using LdHWT than SdHWT (64%), most likely because the long duration treatment satisfies quarantine requirements in all Australian jurisdictions and controls endogenous pathogens, in addition to the external pathogens controlled by SdHWT. Four respondents gave reasons for not currently using HWT, two because of safety concerns and two because they did not have on-site HWT plants.

Grower perceptions of the efficacy of HWT in controlling grapevine pests and diseases are summarized in Table 1. A majority of growers agreed that LdHWT provided some level of control for internal and external pests and diseases and a majority also were of the opinion that SdHWT provided some level of control for external pests and diseases. The number of respondents who did not believe in the efficacy of either HWT was very small. However, a significant level of doubt about the efficacy of HWT among nursery operators is indicated by the substantial number of respondents who ticked either the" *frequently*" or "*sometimes*" response options. This uncertainty might have arisen as a result of variable results from poorly applied hot water treatments, or

Table 1. Grower perception of the efficacy of hot-water treatment for pathogen control expressed as a percentage of whole respondent cohort.

Activity	Long duration HWT (%)			Short duration HWT (%)		
	Always	Frequently/ sometimes	Never	Always	Frequently/ sometimes	Never
Controls internal pests and pathogens	36	52	8	NAa	NA	NA
Controls external pests and pathogens	52	44	0	40	44	4

[a] NA short duration HWT is not recommended for control of internal pests and pathogens.
Note: not all respondents answered these questions.

from a lack of clear, concise and unambiguous information regarding the efficacy of HWT (Vanclay and Lawrence, 1994).

Scientific research that investigates the efficacy of HWT against endogenous pathogens including phytoplasmas (Caudwell *et al*., 1997) trunk disease pathogens (Crous *et al*., 2001; Rooney and Gubler, 2001; Whiting *et al.*, 2001; Fourie and Halleen, 2004b; Gramaje *et al*., 2009a) is generally published in peer reviewed journals which are not normally read by industry, or is reported in technical magazines aimed at the wine industry more broadly (Waite, 1998; Waite *et al*., 2001; Crocker *et al*., 2002), rather than directly at the vine nursery industry. The terminology used in the scientific literature and conference presentations may also be a source of confusion, particularly the term "*control*". In scientific literature control often means that the target pest or pathogen cannot be detected in the treated material, but stops short of claiming that the treatment eliminates the target pest or pathogen. This may suggest to some readers that the treatment is not fully effective. In the 1990s and early 2000s both the Australian Vine Improvement Association and the Vine industry Nursery Association conducted more than ten HWT workshops across all states, specifically for the vine nursery industry, aimed at addressing these issues, but not all nursery operators were represented at these workshops and, as yet, no manual or reference book has been published specifically aimed at assisting nursery operators in relation to this issue.

Most nursery operators were less sanguine about the safety of HWT. A substantial number felt that LdHWT was never a safe treatment for cuttings (24%) or rooted vines (32%). Fewer thought that LdHWT was always or frequently a safe and reliable treatment for cuttings (28% and 20% respectively). Confidence in LdHWT for rooted vines was even lower. Only 8% of respondents thought that it was always a safe and reliable treatment and only three felt it was frequently safe and reliable. SdHWT was viewed slightly more favourably. Only 16% and 12% of respondents respectively took the view that SdHWT was never a safe and reliable treatment for cuttings and rooted vines. More respondents (24% and 32% respectively) thought SdHWT was always or frequently a safe and reliable treatment for cuttings and rooted vines.

Respondents also had the opportunity to make any general comments at the end of the survey. Of the 64% of respondents who exercised this option, 36% commented about HWT. Negative comments were made by 20% of the respondents and included remarks such as: 1) "*HWT for interstate vines has cost us a fortune in failed vines. HWT cuttings is (sic) avoided like the plague for losses of up to 100% at times. Never again*"; 2) *"I heard a colleague say once when investigating HWT and finding no real hard evidence to provide benefit, that HWT is like treating everyone in the community with chemotherapy in case they have cancer*"; 3) "*My belief is that HWT exacerbates any other problems the vines may have to a high degree. E.g. Healthy vines may experience 5% loss in take. Problem vines may experience 50% loss in take*". However, four respondents indicated that they thought other factors either directly affected propagation success or the success of hot water treated material. Comments included: 1) "*Look beyond the HWT treatment for most of the issues with grafting, e.g. quality of cuttings*"; 2) "*stress of plant material needs to be considered, e.g. frost, dryness, heavy crop*"; 3) *"We have found out that cool room temperature is most important and planting as soon as possible after coming out of cold room"* (sic).

A majority of respondents (72%) thought that some *V. vinifera* varieties were more sensitive to HWT than others and only 12% respondents thought that there were no differences between varieties. By contrast, those who believed that some rootstock varieties were more sensitive than others (32%) were in the minority. Eleven respondents felt that there was no difference in the sensitivity of rootstocks to HWT and the remaining 12% of respondents either did not reply to the question or stated that they did not know. The *V. vinifera varieties* Pinot Noir, Chardonnay, Merlot, Riesling, Petit Verdot and the rootstock varieties Ramsey and Ruggeri 140 were identified as being sensitive to HWT. These results agree broadly with anecdotal reports and research results (Crocker *et al.*, 1997).

Negative effects of HWT that have sometimes been observed by growers, or reported previously, include delayed callusing and rooting of cuttings (Orffer and Goussard, 1980; Waite and May, 2005), delayed development or death of buds in cuttings and rooted vines (Wample, 1993; Caudwell *et al*., 1997; Laukart *et al*., 2001; Gramaje *et al.*, 2009a), failed or incomplete healing of graft unions and fermentation in cold storage. However, the response of cuttings and vines is variable and other authors reported no negative effects of HWT on treated material (Ophel *et al.*, 1990; Fourie and Halleen, 2004). Sixteen respondents reported negative effects of HWT on cuttings (Table 2); 52% reported problems with grafted cuttings and 11 reported negative effects on rooted vines. The most commonly reported effects of HWT were delayed development of callus (44%) and roots (48%), delayed bud development (44%), death of buds (44%) and death of whole cuttings in the nursery (40%) There were fewer reports of deaths of one-year-old grafted or ungrafted vines in the vineyard (24% and 36% respectively). This might be a reflection of lower rates of treatment in rooted vines than in cuttings rather than of a difference in sensitivity between cuttings and rooted vines. Anecdotal reports indicate that many nurseries avoid treating one-year-old rooted vines for fear of litigation if the vines die or perform poorly in the vineyard. However, two of the respondents who agreed to a telephone interview commented that they thought rooted vines were generally less susceptible to injury from HWT than were cuttings and that this was a general perception in the nursery industry. It is notable that reports of HWT cuttings and rooted vines fermenting in cold storage were less frequent than other forms of injury (20% and 12% reports respectively). Anecdotally this is seen as being a common problem, but respondents to telephone interviews commented that fermentation in cold storage had declined in recent years as a result of better cool room management practices and improved sanitation.

Survey Part II – Other nursery practices

The second part of the survey examined if other potentially harmful practices were widespread among Australian nurseries. The quality and disease status of source material, cool room management, packaging and general nursery sanitation all affect the viability of hot water treated cuttings or vines (Waite and May, 2005). The water used in HWT and other process such as hydration (the practice of soaking cuttings in water for variable periods) is a potential source of contamination (Fourie and Halleen, 2006; Retief *et al*., 2006; Whiteman *et al*., 2007; West *et al*., 2010) and physiological stress.

Origins of cuttings

Vine improvement associations have been formed in all wine producing states to select and disseminate high quality propagating material for the wine industry. The Australian Vine Improvement Association (AVIA) is the peak national body. These associations provide high health, true to type certified cuttings to the vine nursery industry. These cuttings are generally regarded as being the best available material compared to cuttings from unregistered vineyards where disease status and type are not able to be verified. However, there are reports of nurseries obtaining cuttings from unregistered sources, usually as a result of a shortage of registered material. There are also reports that some nurseries on-sell surplus cuttings to other nurseries. Cuttings sourced from outside the vine improvement associations, or cuttings that have passed through a number of hands are more likely to be affected by diseases and environmental stress and potentially less able to tolerate HWT and other stresses imposed during propagation (Hartmann *et al*., 1990b). A narrow majority (56%) of nurseries that responded to the survey stated that they "*frequently*" use registered cuttings from vine improvement associations, only five nurseries reported that they "*always*" use registered

Table2. Respondents reporting of negative effects of hot-water treatment on cuttings and rooted vines.

Symptoms of HWT Sensitivity	%
Slow or delayed callusing of V. vinifera cuttings	44
Slow or delayed rooting of V. vinifera cuttings	48
Unusually high deaths of buds in V. vinifera cuttings	44
Slow or delayed bud burst in V. vinifera cuttings	44
Unusually high deaths of V. vinifera cuttings in cold storage	24
Unusually high deaths of HWT V. vinifera cuttings in the nursery	40
Slow or delayed healing of graft unions	32
Incomplete healing of graft unions	24
Slow or delayed rooting of bench grafted vines	24
Slow or delayed scion bud burst in newly grafted vines	32
Unusually high deaths of scion buds in newly grafted vines	28
Slow or delayed bud burst in one-year-old vines	32
Unusually high deaths of roots in one-year-old vines	28
Unusually high deaths of one-year-old vines in cold storage	24
Unusually high deaths of HWT one-year-old own rooted vines in the vineyard	24
Unusually high deaths of HWT one-year-old grafted vines in the vineyard	36

material. More than half the respondents (56%) also reported obtaining registered cuttings from third parties rather than directly from the original supplier. It is evident from these responses that the quality of cuttings entering the propagation chain is highly variable and this may have consequences in terms of predictability of response to HWT and other nursery processes.

Hydration of cuttings and rooted vines

Repeatedly soaking cuttings, pre-cut buds and also rooted vines in water in the belief that it reverses the effects of dehydration and promotes root initiation is a widespread practice in grapevine nurseries. The origin of soaking as a routine practice in grapevine nurseries appears to be a paper by Spiegel (1954) who reported that prolonged hydration (up to 96 h) of rootstock and *V. vinifera* cuttings improved rooting by leaching auxin inhibitors. However, Spiegel (1954) also reported that these inhibitors disappeared naturally as the cuttings emerged from dormancy in spring after exposure to natural or artificial chilling, thus obviating the need for soaking.

Despite this, the practice remains entrenched in grapevine nurseries around the world.

In nurseries that propagate other species, every effort is made to prevent dehydration of cuttings, untreated water is not used and cuttings are not soaked for fear of cross contamination and creating conditions favourable to pathogens such as *Pythium* spp. *Rhizoctonia* spp. and *Botrytis cinerea* that kill cuttings during the callusing and rooting phase (Baker, 1957; Hartmann *et al*., 1990a; Preece, 2003). Trunk disease pathogens including *P. chlamydospora* (Fourie and Halleen, 2004a; Retief *et al*., 2006; Whiteman *et al.,* 2007), Botryosphaeriaceous specie and *black foot fungal agents* have been detected in cuttings (Giménez-Jaime *et al*., 2006) and DNA of both *P. chlamydospora* (Edwards *et al*., 2007) and *Phaeoacremonium* spp. (Aroca *et al.*, 2010) has been detected in soaking water sampled from hydration tanks in commercial grapevine nurseries, evidence that hydrating tanks are a potential source of cross contamination.

The value of soaking has been questioned by researchers for more than a decade (Crocker *et al*., 2002; Fourie and Halleen, 2006; Retief *et al*., 2006), but the survey results indicate that the practice is still widespread. All respondents reported soaking material at least once during the propagation cycle and the majority (76%) reported soaking material on three or more occasions. Soaking times varied from less than 1 hour to more than 12 hours (most commonly less than eight hours). One respondent reported soaking one-year-old rooted vines for more than 12 hours on four occasions (following lifting from the field nursery, before cold storage, after cold storage and before despatch to customers). Although clean water was used by all respondents, there are ample opportunities for cross contamination from bark inhabiting organisms that enter the water during soaking if the active chemical has dissipated, or been inactivated by soil and organic material on the surfaces of the treated cuttings and vines. Thus hydration continues to threaten the phytosanitary status of grapevine planting material in Australia.

Cold storage conditions

Cold storage at 1–3°C is a convenient way of storing dormant cuttings (Hartmann *et al*, 1990b). Cold storage delays root initiation and bud burst in cuttings and enables nurseries to extend the propagating season by several weeks, and make better use of labour, and has largely replaced the practice of storing cuttings in sand or sawdust callusing pits. However, poorly managed cool rooms can be the source of microbial and chemical contamination and of stress from temperature fluctuations. A majority of nurseries reported always using on site cool rooms for storing cuttings and one-year-old vines (56% and 40% respectively). Off site cool rooms operated by third parties were also utilized; 16% of respondents always used off site cool rooms for storing cuttings and 24% of respondents always used off site cool rooms for storing one-year-old vines. A majority of respondents (72%) reported always monitoring cool room temperature to ensure temperatures remained within the range of 1–3°C, but only four respondents reported always monitoring the temperature inside bins or crates. However, another 36% of respondents reported that they either "*frequently*" or "*sometimes*" monitored the temperature inside bins or crates indicating that there is a level of awareness that storage temperature affects the quality of the stored material and that the temperature in a bin of cuttings may differ from the cool room atmosphere.

There is also an awareness of the importance of cool room sanitation. The majority of respondents (72%) reported cleaning on site cool rooms at the beginning of the propagating season, but off site cool rooms operated by third parties were rarely cleaned by survey respondents (20% of those using off-site cool rooms). Cleaning of on-site cool rooms was usually relatively thorough. Floors were swept and walls and floors were washed, usually with chlorine based disinfectants, but the cleaning of storage bins and crates was less common because they were not seen as potential sources of contamination. Eight respondents stated that there was no need to clean bins and crates because they lined them with new plastic bags, or packaged cuttings and one-year-old vines in new plastic bags. Responses such as; *"Have crates that are only used for cuttings storage"* and "*No. Because we use new plastic liners in packs or bins. Our hydration tanks are regularly disinfected with appropriate chemicals"* demonstrated a relatively poor understanding of microbial ecology and epidemiology. However, others demonstrated a much better grasp of these issues with replies such as; *"Steam sterilization 75°C for 30 min"* and *"Before use, bins are pressure washed and soaked in chlorinated water".*

Materials other than cuttings or vines can also be a source of contaminants in cool rooms, particularly if atmospheres are shared with vegetables such as potatoes and onions treated with sprouting inhibitors, or climacteric fruits such as apples that produce ethylene, a hormone associated with senescence in plants (Saltviet, 1999; Pierik *et al*., 2006) that may also prompt emergence from dormancy (Ophir *et al*., 2009); undesirable in long term storage where the purpose is to delay sprouting. Only 28% of respondents reported storing other materials (beer, vegetables and deciduous fruits) with cuttings and vines indicating that the risks from these sources of contamination while high, particularly if fruits and vegetables are stored with vines, the problem is not common and therefore not a major cause of cutting and vine failure across the nursery industry.

The move from callusing pits to cold storage entailed significant changes to packaging. The risk of dehydration in cold storage resulted in the use of sealed plastic bags for cutting storage. The unintended consequences of this were the development of anaerobic conditions and excessive growth of surface moulds. A moderate exposure to anoxia can result in enhanced bud burst (Halaly *et al.*, 2008; Ophir *et al.*, 2009), but decreasing oxygen levels, accumulation of toxic fermentative metabolites, and the growth of anaerobic microorganisms (Phillips, 1996) can result in fatal tissue damage when material is stored for 3–6 months in bags with limited head space (Chen *et al.*, 2011). Storage in bags with a small number of perforations (6–8) made with a ball point pen or instrument of similar diameter is recommended to allow some air flow without causing excessive dehydration if cool rooms are not humidified, but anecdotal reports indicate that sealed bags are common. Five respondents reported using sealed bags and seven used perforated or unsealed bags, but a number of others did not state whether the bags they used were sealed or unsealed, perhaps indicating that they did not see this as an important detail. More precise data may have been elicited by designing the question with fixed choices (Miles and Huberman, 1994). However, the survey results do show that the approach to packaging and cold storage is inconsistent and likely contributes to the variable quality of planting material.

Use of chemical control

Chemical sprays, dips and drenches that are widely used in the nursery industry to control the fungal pathogens including *Botrytis cinerea* that are favoured by the warm, moist and sheltered nursery environments (Daughtry and Benson, 2005) are also employed by the vine nursery industry. and commonly used fungicidal dips including captan, carbendazim and didecyldimethylammonium chloride can also assist in reducing infection by trunk disease pathogens including "*Cylindrocarpon*" spp. (Alaniz *et al.*, 2011), *P. chlamydospora* and *Phaeoacremonium* spp. (Fourie and Halleen, 2004b; Gramaje *et al.*, 2009b). In this survey, only 12% of nurseries reported not using fungicides at any of the stages in the propagation process. Of the remaining 88% of nurseries, 64% used fungicides more than twice, but only 8% used fungicides at all stages of the cycle; in hydrating tanks, in callusing boxes, as a dip for stored cuttings and one-year-old vines and as a dip before despatch to customers. The use of more than one type of fungicide was reported. Captan was the most commonly used fungicide, but iprodione, mancozeb, carbendazim, 8-hydroxyquinoline sulphate (Chinosol), the biocontrol agent *Trichoderma* and the multipurpose biocides didecyldimethylammonium chloride (Sporekill) and sodium chlorite (Vibrex) were also used. Two nurseries also reported using benomyl, a fungicide that is no longer registered for use in Australia.

Discussion

While the small actual numbers and the self selecting nature of respondents prevent a comprehensive statistical analysis, the survey has provided a useful insight into the vine nursery industry in Australia and the factors that influence the quality of planting material. Our results have revealed wide variations in practices both within and between nurseries and confirmed the previous anecdotal evidence that reliability, and efficacy of HWT continues to be questioned by a majority of nursery operators. The literature examining the effects of heat treatment on plant physiology is not large and there is a need for further research on the effects of HWT on the growth and development of cuttings, particularly *V. vinifera*, before the concerns of the nursery industry can be fully answered. By contrast, the consistent use of treated water and fungicides and other sanitary practices demonstrate a better than expected, although imperfect, understanding of factors that can lead to microbial contamination and consequent loss of quality. However, the common thread running through all the responses is the inappropriate use of soaking (often coupled with poor storage practices) that is likely to be a major source of contamination regardless of when it is applied during the propagation process. Respondents seemed to be generally unaware that cuttings and vines themselves, as well as untreated water, can be a source of contamination from bark inhabiting pathogens that can gain entry through propagation wounds, affecting the short and long term health and vigour of the vine. A small experiment to quantify and illustrate this point would be a useful precursor to the development of improved propagation protocols, as would an investigation into the appropriate use and choice of fungicides. However, there is no need for comprehensive research in nursery sanitation. The value of good sanitation in plant nurseries has been known since the 1950s when the first editions of the seminal works on modern nursery practice "The UC System for Producing Healthy Container Grown Plants" (Baker, 1957) and "Plant

Propagation Principles and Practices," (Hartmann and Kester, 1959) were published.

Vine nurseries do not usually belong to the Nursery and Garden Industry Australia association and therefore do not utilize the best practice management guides attached to the accreditation scheme of that organization. They rather belong to the Vine Industry Nursery Association that has not yet completed development of similarly comprehensive guidelines. If the quality and consistency of grapevine planting material is to improve to the standard required for the establishment of healthy, productive, long lived vineyards it is in the interest of all participants in the grape and wine industries to support the development of comprehensive propagation procedures for incorporation into accreditation schemes as a matter of urgency. Until such time, the current *ad hoc* approaches to nursery practice are likely to persist and the quality of planting material will continue to be erratic. However, it will not be sufficient to simply codify a set of standard operating procedures and expect them to be adopted. The benefits of standard operating procedures to the nurseries themselves must also be clearly demonstrated (Vanclay and Lawrence, 1994) and the principles of good nursery practice be explicitly stated to ensure that nursery operators understand the reasons for, and the importance of, each sequential step in the propagation process (Baker, 1957; Hartmann *et al*., 1990a). It is also essential that codified standard operating procedures be practical and flexible enough to accommodate the needs and resources of individual businesses without compromising the quality of the end product. It is only by a comprehensive approach that engages, and is supported by, all interested parties that the quality of grapevine planting material will meet the standard required for the production of high quality grapes and wine.

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