RESEARCH PAPER

Soaking grapevine cuttings in water: a potential source of cross contamination by micro-organisms

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Summary. Grapevine nurseries soak cuttings in water during propagation to compensate for dehydration and promote root initiation. However, trunk disease pathogens have been isolated from soaking water, indicating cross contamination. Cuttings of Vitis vinifera cv. Sunmuscat and V. berlandieri x V. rupestris rootstock cv. 140 Ruggeri were immersed in sterilized, deionised water for 1, 2, 4, 8 and 16 h. The soaking water was cultured (25°C for 3 days) on non-specific and specific media for fungi and bacteria. The base of each cutting was debarked and trimmed and three 3 mm thick, contiguous, transverse slices of wood cultured at 25°C for 3 days. The soaking water for both cultivars became contaminated with microorganisms within the first hour. Numbers of fungi isolated from the wood slices soaked for one hour were significantly greater than those from non-soaked cuttings. The number of bacterial colonies growing from the wood slices increased after soaking for 2–4 h in Sunmuscat. In a second experiment Shiraz cuttings were soaked for 1, 2, 4, 8 and 24 h. The soaking water became contaminated within the first hour but only the bacterial count increased significantly over time. Microorganisms also established on the container surfaces within the first hour although there were no significant increases over 24 h. These results confirm that soaking cuttings is a potential cause of cross contamination and demonstrate contamination of cuttings occurs after relatively short periods of soaking. Avoiding exposing cuttings to water will reduce the transmission of trunk diseases in propagation.

Key words: trunk diseases, soaking, cross contamination, grapevine propagation.

Introduction

In modern times the grapevine propagation process has been mechanized and streamlined, enabling individual nurseries to reduce costs and produce large numbers of vines over an extended season. Bench mounted grafting machines that automatically cut and join a dormant rootstock cutting and one bud scion prior to rooting, along with cool rooms to hold cuttings in the dormant state until required for grafting, are now common in the grapevine nursery industry. Bench grafting, as this technique is known, has enabled individual nurseries to produce many hundreds of thousands of vines in a single season. However, the efficiency gains resulting from mechanization and the use of cool rooms have been somewhat offset by losses in quality. Incompletely healed graft unions and biotic contamination of the rootstocks, scions and graft unions are common problems in bench grafted vines (Stamp, 2001) and spasmodic, large scale failures of grafted vines in the nursery and vineyards are a serious problem for nurseries and grape growers (Morton, 2000; Halleen et al., 2003; Gramaje and Armengol, 2011; Whitelaw-Weckert et al., 2012).
The large scale vine failures that occur soon after planting have been attributed to infection by trunk disease pathogens (Rego et al., 2000; Sidoti et al., 2000; Gramaje and Armengol, 2011), pointing to propagation as a potential source of infection in young vines (Whitelaw-Weckert et al., 2012). There is indirect evidence that contaminating microorganisms enter the propagation chain in (Halleen et al., 2003; Whiteman et al., 2007), or on (Whiteman et al., 2004a), asymptomatic cuttings from infected mother vines and contaminate other cuttings via water used to soak cuttings during propagation (Rego et al., 2001; Edwards et al., 2007, 2011; Aroca et al., 2010).

In addition, Rahnella aquatilis, Enterobacter intermedius and Trichosporon pullulans, microorganisms that are not recognised grapevine pathogens but are associated with dust and faecal contamination of water, have been isolated from compromised vine tissues and have also been shown to interfere with graft healing and to inhibit shoot growth (Waite and Cole, 2006). Botryosphaeriaceae spp. (Phillips, 2002) and Phaeomoniella chlamydospora (Wallace et al., 2004) are also reported to interfere with graft healing.

Grapevine nurseries routinely soak many hundreds of cuttings together in water as a means of compensating for dehydration that occurs during cutting harvest and transportation to nurseries (Fourie and Halleen, 2006; Waite and Morton, 2007; Gramaje and Armengol, 2011). Soaking occurs for periods typically between 1 and 12 hours, though sometimes for longer, and is often performed more than once during the propagation cycle.

Soaking is thought to facilitate the entry of epiphytes into cutting tissue through the wounds made at each end of the cuttings, disbudding wounds and graft unions (Whiteman et al., 2004b; Fourie and Halleen, 2006; Retief et al., 2006; West et al., 2010) and has been implicated in cross contamination by the trunk disease pathogens Ca. luteo-olivacea, Pa. chlamydospora and Phaeoacremonium aleophilum (Gramaje et al., 2009, 2011). Some of these organisms have been detected in nursery environments. Pa. chlamydospora DNA has been detected in untreated rainwater collected from the roofs of houses and sheds that is used in Australian nurseries in hydration tanks, hot water treatment tanks and post HWT cool down tanks (Edwards et al., 2007) and in pre storage fungicide/rehydration tanks and pre grafting hydration tanks in New Zealand nurseries (Whiteman et al., 2004b). Retief et al. (2006) also detected Pa. chlamydospora in a high percentage of water samples collected after pre-storage hydration (40%) and during grafting (67%) in South African commercial nurseries. Phaeoacremonium spp. were also detected using molecular techniques in post-storage hydration tanks in Spanish nurseries (Aroca et al., 2010) and species of Botryosphaeriaceae and Petri disease pathogens (Pa. chlamydospora and Phaeoacremonium spp.) were detected by PCR on the surface of grafted varieties and rootstocks and in hydration and callusing baths in French nurseries (Vigues et al., 2009). In Italy, Pollastro et al. (2009) detected Pa. chlamydospora DNA in 28% of pre-grafting and 23% of pre-callusing hydration tanks. Viable propagules of Ca. luteo-olivacea were also obtained from hydration tanks in Spanish nurseries by filtering the water samples and culturing the filtrate on appropriate media (Gramaje et al., 2011).

Some nurseries use fungicides in the soaking water, but their efficacy cannot always be relied upon (Fourie and Halleen, 2004), particularly if multiple batches of cuttings are soaked in the same fungicidal dip. Apart from Pa. chlamydospora (Pascoe and Cottral, 2000) and Botryosphaeriaceae spp. (Billones-Baaijens et al., 2013) many more microorganisms including bacteria are also found on the surfaces of grapevines (Munkvold and Marois, 1993). The potential for endophytic microorganisms to suppress pathogens in grapevine wood tissue has been raised by several authors (Martini et al., 2009; Gonzáles and Tello, 2010), but knowledge of the influence of endophytes on the development of diseases is incomplete (Crous et al., 2001; Gonzáles and Tello, 2010) and previously unidentified microorganisms might be opportunistic pathogens when accidentally introduced into the tissues of vines when cuttings are soaked. Although it is probable that the cuttings themselves are a major source of microbial contaminants identified in soaking water, particularly if potable water is used, this has not been tested.

To determine the capacity of epiphytic microorganisms to contaminate soaking water and thus the wood of cuttings, we investigated the rate of movement of microorganisms into soaking water and the woody tissue of cuttings at different soaking intervals. We also investigated the ability of microorganisms to form bio-films on surfaces of soaking vessels and thus present a potential contamination threat to subsequent batches of cuttings; an issue raised by the nursery supplying the cuttings for the first experiment.
Materials and Methods

Microbial contaminants in soaking water and woody tissue

Healthy, dormant cuttings (approximately 8 mm diameter) of *V. vinifera* cv. Sunmuscat and rootstock 140 Ruggeri from the Sunraysia district of the Murray Valley were obtained from a New South Wales vine nursery in September 2010. The cuttings were held in cold storage at 2–3°C at the nursery between harvesting in early winter (June) and shipping in September. Cuttings were trimmed to size (300 mm, approximately 19 g) with fresh cuts 10 mm above the top bud and 5 mm below the bottom bud. The freshly trimmed cuttings were randomly divided between 3 replicates of 6 soaking treatments (0, 1, 2, 4, 8 and 16 h) per variety with 3 cuttings per replicate. Cuttings were completely submerged in sterile (autoclaved at 131°C for 30 min at 2770 mbar) deionised water to a depth of 30 mm (0.5 L/cutting as per industry standard) at ambient room temperature (18°C) in sterile plastic containers (260 × 180 × 90 mm) with loosely fitting lids. Sterile deionised water was used in these experiments to allow the assays to be standardized as domestic supply water varies widely in pH and the ions present over time and between regions (Batarseh, 2006).

A 50 mL sample of water was taken from each treatment replicate using sterile plastic centrifuge tubes (30 mm diameter) after agitation with a sterile spatula to ensure the water was well mixed and all levels of water were sampled. Immediately prior to sub-sampling the 50 mL aliquots were vigorously inverted several times and vortexed for 20 seconds to ensure even mixing. After a preliminary trial to determine appropriate dilutions, three replicate 30 μL aliquots of undiluted sample water and sample water diluted to 10⁻¹ in phosphate-buffered saline (PBS) were spread plated onto selective media for fungi [Dichloran Rose Bengal Chloramphenicol (DRBC) agar, Oxoid], bacteria [Nutrient agar (Oxoid) with 30 ppm benomyl (NA-B)] and *Pseudomonas* agar (Oxoid) for *Pseudomonas* spp., and the non selective fungal medium potato dextrose agar (PDA, Oxoid) and incubated in darkness at 25°C for 3 days and the number of colony forming units (cfu) counted.

Following soaking treatments, the cuttings were debarked and surface sterilized by flaming briefly with ethanol (70%). The base of each cutting was trimmed by 3 mm and three contiguous 3 mm thick cross sections taken from the base of each cutting and incubated in darkness on PDA at 25°C. After 3 days incubation, the numbers of fungal and bacterial colonies emerging from the wood were counted. The cfu g⁻¹ (Cg) was calculated using equation 1:

\[
C_g = \frac{C_c}{S}
\]

where Cc is the number of cfus per slice and S (g) is the weight of the slice.

Formation of biofilms

Arising from the comments of the nursery that supplied the cuttings for the first experiment, a second experiment was performed the following season (2011) to determine the capacity of fungal and bacterial epiphytes to form bio-films on the surfaces of soaking vessels and thus become an additional source of contamination for subsequent batches of cuttings soaked in the same container. Australian nurseries use a variety of large vessels for soaking cuttings, usually plastic, stainless steel or galvanised steel all of which can be colonised by microorganisms (Percival et al., 1998; Webb et al., 2000; Ilhan-Sungur and Çotuk, 2010) that can be very difficult to remove from container surfaces (Batté et al., 2003).

For this experiment, cuttings of *V. vinifera* cv. Shiraz were obtained in late June from the Charles Sturt University vineyard at Wagga Wagga, NSW and held for 3 months in cold storage at 2–3°C in ventilated plastic bags with damp paper to prevent dehydration. Cuttings were removed from cold storage, allowed to come to ambient temperature, trimmed to size (300 mm) with fresh cuts 10 mm above the top bud and 5 mm below the bottom bud and randomly divided between 5 soaking treatments (1, 2, 4, 8 and 24 h) per variety with 3 replicates of 3 cuttings per replicate. The cuttings were soaked in sterile deionised water (0.5 L/cutting as per industry standard) in sterile plastic containers with loosely fitting lids.

Following the method used in experiment 1, a 50 mL sample of water was taken from each treatment replicate after stirring and diluted to 10⁻¹ in phosphate-buffered saline (PBS). Three replicate 30 μL aliquots of each diluted sample were spread plated onto selective media for fungi (DRBC) and bacteria (NA-B) and incubated as above before colonies were counted.

Numbers of microorganisms on the inside surfaces of the containers were sampled by draining the
water from the containers and swabbing a 25 cm² area with a sterile cotton swab wetted in 10 mL sterile PBS. The swabs were then aseptically returned to the PBS, agitated vigorously and three replicate 30 μL aliquots spread onto selective media for fungi (DRBC) and bacteria (NA-B) and incubated as above and colonies counted.

Statistical analyses

Culturable microbial concentrations from water samples, container surface swabs and colonies emerging from wood samples were subjected to analysis of variance (ANOVA) test and least significant differences test by Genstat for Windows, 15th Edition.

Results

Microorganisms in soaking water and woody tissue

In this experiment the sterile soaking water of both varieties (Sunmuscat and 140 Ruggeri) became contaminated with *Pseudomonas* bacteria, NA-B bacteria, DRBC fungi and Pda fungi and bacteria within the first hour of soaking (Table 1). Microbial populations in the soaking water of Sunmuscat increased significantly \((P<0.05)\) over the second hour except in populations culturable on NA-B where the increase was not significant. Thereafter populations generally decreased until climbing again in the time between 8 h and 16 h, although the later increases were significant \((P<0.05)\) only for NA-B (bacteria) and DRBC (fungi). In the case of 140 Ruggeri the pattern was somewhat different. The number of microorganisms in soaking water increased in the second hour, but only significantly \((P<0.05)\) in populations culturable on DRBC (fungi) and PDA (mixed populations). Numbers reached a maximum after 4 h of soaking in populations culturable on DRBC (fungi) and PDA (mixed populations) and after 8 h of soaking in populations culturable on PS (Pseudomonads) and NA-B (bacteria). After peaking, there were no significant differences over the time of the experiment in all populations except fungi cultured on DRBC where there was a significant \((P<0.05)\) drop in numbers before beginning to increase again between 8 and 16 h (Table 1).

The cultivable fungal populations in wood samples of both varieties also increased significantly \((P<0.05)\) during the first hour of soaking, but then remained

<table>
<thead>
<tr>
<th>Culture media</th>
<th>1 (10^4) cfu mL(^{-1})</th>
<th>2 (10^4) cfu mL(^{-1})</th>
<th>4 (10^4) cfu mL(^{-1})</th>
<th>8 (10^4) cfu mL(^{-1})</th>
<th>16 (10^4) cfu mL(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>140 Ruggeri</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PS</td>
<td>0.57 ± 0.49</td>
<td>3.34 ± 1.80</td>
<td>6.73 ± 3.80</td>
<td>7.79 ± 4.58</td>
<td>4.11 ± 1.38</td>
</tr>
<tr>
<td>NA-B</td>
<td>0.95 ± 0.78</td>
<td>3.66 ± 1.56</td>
<td>6.50 ± 4.17</td>
<td>10.78 ± 8.56</td>
<td>6.21 ± 2.98</td>
</tr>
<tr>
<td>DRBC</td>
<td>0.04 ± 0.01 b</td>
<td>5.84 ± 3.19 a</td>
<td>6.02 ± 0.53 a</td>
<td>1.12 ± 0.59 b</td>
<td>2.01 ± 1.18 b</td>
</tr>
<tr>
<td>PDA</td>
<td>0.50 ± 0.40 c</td>
<td>3.90 ± 2.68 b</td>
<td>7.51 ± 1.34 a</td>
<td>4.49 ± 0.27 ab</td>
<td>6.13 ± 2.14 ab</td>
</tr>
<tr>
<td>Sunmuscat</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PS</td>
<td>1.20 ± 0.24 c</td>
<td>10.59 ± 1.55 a</td>
<td>3.11 ± 0.62 b</td>
<td>1.76 ± 0.28 bc</td>
<td>2.90 ± 0.45 b</td>
</tr>
<tr>
<td>NA-B</td>
<td>1.18 ± 0.20 b</td>
<td>17.90 ± 8.75 ab</td>
<td>5.11 ± 1.06 b</td>
<td>4.09 ± 0.55 b</td>
<td>13.69 ± 2.27 a</td>
</tr>
<tr>
<td>DRBC</td>
<td>0.74 ± 0.25 b</td>
<td>5.46 ± 1.45 a</td>
<td>1.83 ± 0.78 b</td>
<td>2.30 ± 1.67 b</td>
<td>7.14 ± 2.71 a</td>
</tr>
<tr>
<td>PDA</td>
<td>2.26 ± 0.34 c</td>
<td>14.02 ± 6.52 a</td>
<td>5.77 ± 0.47 bc</td>
<td>7.74 ± 1.14 b</td>
<td>10.15 ± 3.55 ab</td>
</tr>
</tbody>
</table>

* For data in a single row, values followed by the same letter are not significantly different \((P<0.05)\).
Soaking vine cuttings: a source of cross contamination

Figure 1. Fungi and bacteria isolated from rootstock 140 Ruggeri and V. vinifera cv. Sunmuscat after different periods of soaking. Vertical bars are the standard error of the means. Letters are for comparison of means of fungal colonies (a, b) and bacterial colonies (X, Y). Bars with a different letter are significantly different according to the Student’s Least Significant Difference (P<0.05).
largely static for the duration of the experiment, although there was a significant ($P<0.05$) increase in fungal colonies in the 140 Ruggeri after 16 h (Figure 1). There were also increases in the number of bacterial colonies isolated from the wood of both varieties, but the increases were not significant until the cuttings had been soaked for 8 h (Figure 1).

Although the titre of all microorganisms in the woody tissue of both 140 Ruggeri and Sunmuscat increased over the time of the experiment, the rate at which the epiphytic microorganisms on the bark of cuttings moved into the soaking water and thus the woody tissue of soaked cuttings varied with variety and type of microorganism. It is interesting to note that despite the high titre of culturable bacteria (NA-B) in the soaking water of both varieties compared to the number of culturable fungi (DRBC) (Table 1), the numbers of fungi isolated from the wood of Sunmuscat and 140 Ruggeri were significantly ($P<0.05$) greater than the numbers of bacterial isolated from the wood of both varieties (Figure 1). The rate of increase in the titre of bacteria isolated from the wood of both varieties was also slower than the rate of increase in the titre of fungi in the wood.

### Microorganisms on container surfaces

In this experiment, only the NA-B bacterial count in the Shiraz soaking water increased significantly ($P<0.05$) beyond the initial contamination that occurred in the first hour of soaking (Table 2). Bacterial and fungal populations became established on the surface of the soaking container within the first hour of the commencement of soaking, followed by non-significant increases for fungi ($P=0.173$) and NA-B bacteria ($P=0.053$) over the time of the experiment (Table 3). These upward trends indicate that the increases in the populations, particularly of bacteria, are likely to have become significant if the experiment had continued for longer.

### Discussion

All healthy plants, including grapevines, are colonised by a diverse range of bacteria, fungi and yeasts that inhabit both the phylloplane and the internal tissues (Bell et al., 1995; Halleen et al., 2003; West et al., 2010). These epiphyte and endophyte communities vary between plant species and with environment-

### Table 2. Colony forming units (cfu) of bacteria and fungi isolated from soaking water of Shiraz cuttings.

<table>
<thead>
<tr>
<th>Culture medium</th>
<th>Soaking time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 10^4 cfu mL⁻¹</td>
</tr>
<tr>
<td>NA-B</td>
<td>3.66 ± 2.40 c</td>
</tr>
<tr>
<td>DRBC</td>
<td>0.26 ± 0.12</td>
</tr>
</tbody>
</table>

For data in a single row, values followed by the same letter are not significantly different ($P<0.05$).

### Table 3. Colony forming units (cfu) of bacteria and fungi recovered from the surfaces of containers used for soaking Shiraz cuttings.

<table>
<thead>
<tr>
<th>Culture medium</th>
<th>Soaking time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 10^2 cfu cm⁻²</td>
</tr>
<tr>
<td>NA-B</td>
<td>15.64 ± 10.56</td>
</tr>
<tr>
<td>DRBC</td>
<td>1.60 ± 0.35</td>
</tr>
</tbody>
</table>
tal conditions (Quadt-Hallmann et al., 1997; Yang et al., 2001; Compant et al., 2005b). Endophytes normally gain entry through roots, and the aerial parts of plants including stomata and flowers (Sette et al., 2006) and although some are pathogenic, many form complex symbiotic relationships with the host plants (Compant et al., 2005a; Rodriguez et al., 2009). In the case of grapevine propagation, the DNA and prop- agules of known grapevine pathogens have been isolated from water used to soak cuttings at various stages of the propagation process (Whiteman et al., 2004a; Retief et al., 2006; Edwards et al., 2007; Aroca et al., 2010), potentially causing cross contamination of entire batches of cuttings by exposing the wounds necessarily made during propagation to the patho-gens in the water (Waite and Morton, 2007).

We have now established a direct link between soaking grapevine cuttings in water at the beginning of the propagation chain and immediate increases in the titre of microorganisms in the bases of cuttings and demonstrated that contamination of cuttings oc- curs after relatively short periods of soaking, thus confirming that soaking cuttings is a cause of cross contamination during propagation.

A number of other interesting observations arising from this work highlight the complex and dy-namic nature of microbial epiphyte and endophyte populations (Ramey et al., 2004; Whipps et al., 2008). Although numbers of culturable fungi isolated from the wood of Sunnuscat and 140 Ruggeri were signif- icantly (P<0.05) greater than the numbers of cultur- able bacterial isolated from the wood of both varie- ties the bacterial numbers in the soaking water were generally greater than the fungal numbers (P<0.05). This was also true for the second experiment where numbers of bacteria in the soaking water were high- er than the numbers of fungi (Table 2). The higher levels of wood colonization by fungi than bacteria may have been a reflection of lower suitability of the woody tissue as a substrate for bacteria, greater ca-pacity of fungi to adhere to and colonize the wood of the cuttings, or antagonistic interactions between the two groups of microorganisms (Ramey et al., 2004). Suppressive interactions within and between fungal and bacterial endophyte populations are well known (Compant et al., 2005a; Sette et al., 2006; Berg, 2009; Rodriguez et al., 2009).

The factors causing the fluctuations in the size of soaking water microbial populations within and between sampling times are likely to have arisen from a number of sources including: differences in micro-bial populations between the cuttings used in each replicate; microbial settling due to gravity between the end of agitation and sample collection (Hornby, 1969); variations in solute concentrations due to sub-strates leaching from the cuttings into the soaking water; and changes in population dynamics resulting from interactions between the different groups within- in the microbial populations (Mian et al., 1997; Jordan et al., 1999; Yang et al., 2001; Whipps et al., 2008).

Culturable fungal concentrations in the Sunnus-cat soaking water were generally greater than those of 140 Ruggeri. This may be a reflection of different inoculum loads in the source vineyards or the gener-al variability in epiphytes that occurs between plant species (Whipps et al., 2008; Yang et al., 2001). Differ-ences in spray regimes and variations in the suitabil-ity of the bark as a habitat may have caused these differ-ences (Yang et al., 2001; Lindow and Brandl, 2003). Rootstock mother vines are not normally trained on trellises in the manner of V. vinifera scions, but are in instead allowed to sprawl on the ground (Stamp, 2003; Hunter et al., 2004) and it is likely that the differences reflect different fungal populations.

It is possible that much of the epiphyte population could have consisted of fastidious and uncultur-able microflora that did not grow on the media used in this experiment (Yang et al., 2001). Large popula-tions of unculturable epiphytic and endophytic mi-croorganisms associated with grapevines have been revealed by molecular techniques (West et al., 2010) and the possibility of these organisms impacting on the results of this work cannot be excluded.

The significant decline in culturable fungal and bacterial populations in Sunnuscat soaking water after the early initial maxima might be explained by both adsorption to the container surfaces and the death of microbial populations due to the osmotic ef-fects of the sterile water used as the soaking medium and/or the lack of suitable substrate to enable the population of microorganisms associated with this variety to persist (Straka and Stokes, 1957; Mian et al., 1997; Jordan et al., 1999). With the exception of DRBC culturable fungi, the microbial populations associated with 140 Ruggeri generally increased over time. Possible causes may be the increase in microbial sub-strate and reduced osmotic stress caused by leaching of soluble carbohydrates from the ends of the cut-tings that is often observed by the author in rootstock varieties in nurseries following soaking. Lower levels
of suitable microbial substrates may explain the slow increase in the microorganisms in the water of the Shiraz cuttings in the second experiment (Straka and Stokes, 1957; Mian et al., 1997; Jordan et al., 1999).

There is a trend in nurseries to shorten soaking times to less than 8 h to avoid cross contamination, but the fungal concentrations in the water after soaking for 1 hour were sufficient to result in significant increases in endophytic fungi, demonstrating that enough fungi move into the water from soaked cuttings for cross contamination to occur earlier in the soaking cycle than is generally thought.

Most nurseries change the soaking water between batches, but microorganisms established on the container surfaces are a potential source of cross contamination for subsequent batches of cuttings. The upward, but not significant trend in bacterial and fungal populations on container surfaces over the 24 h of this experiment is typical of the colonization patterns that are reported by authors investigating the establishment and growth of biofilms in other situations. Hood and Zottola (1997) reported that after initial colonization of stainless steel surfaces in the first hour of exposure, there was little increase in colonization over time (0-80 h). The authors noted that the adherence of microorganisms to stainless steel surfaces over time varies between species and is influenced by factors such as the growth stage of the organism, substrate availability and other substances, including proteins in the liquid environment. The upward trend in biofilm populations in this experiment is in contrast to the fluctuating populations in the water (Tables 1 and 2). However, biofilm species represent only a subset of the species in the liquid matrix (Costerton et al., 1994; Tait and Sutherland, 2002) and the characteristics and behaviour of microorganisms in an established biofilm are independent of the same species in the liquid matrix. Biofilm populations interact differently and are more stable than the population of origin (Costerton et al., 1994; Hansen et al., 2007).

The slow colonization of the container surfaces reported here may also indicate that plastic is a relatively poor surface for colonization by microorganisms compared to the bark of the cuttings. Factors such as the competition for space between the colonizing microorganisms, the lack of suitable substrate in the water and the osmotic stress imposed by using distilled deionised water may have also affected the rate of colonization (Webb et al., 2000; Chmielewski and Frank, 2003). However, microorganisms are particularly difficult to dislodge from container surfaces with common biocides (Costerton et al., 1994; Batté et al., 2003; Harding et al., 2009) and are therefore potential source of cross contamination in nurseries where successive batches of cuttings or vines are soaked in the same container. This is particularly likely to be the case if soaking time is prolonged (Waite and Morton, 2007; Aroca et al., 2010) and the level of substrates increases (Hood and Zottola, 1997; Chmielewski and Frank, 2003), containers are not thoroughly cleaned between batches and the soaking water is not treated with an active biocide. Commonly used fungicides tested in the vine nursery context can reduce inoculum of known pathogens, particularly Pa. chlamydospora and P. aleophilum in soaking water (Fourie and Halleen, 2006) and cuttings (Retief et al., 2006; Gramaje et al., 2009; Rego et al., 2009) but, these and other general purpose biocides have not been evaluated for the specific purpose of cleaning soaking containers.

The results of this study support the growing body of evidence that soaking water is a source of cross contamination and trunk disease transmission during propagation (Hayman et al., 2004b; Retief et al., 2006; Edwards et al., 2007; Aroca et al., 2010). If untreated water is used there is also potential for other microorganisms that are not known grapevine pathogens, to enter the cutting tissue during soaking and impede shoot growth (Waite and Cole, 2006).

Although fungicides and general biocides used in nurseries have been evaluated against a number of known trunk disease pathogens (Groenewald et al., 2000; Jaspers, 2001; Fourie and Halleen, 2006; Gramaje et al., 2009; Rego et al., 2009), the research on biocides in the nursery context has been outpaced by the identification of pathogens implicated in trunk diseases. Therefore, development of nursery management strategies that avoid exposing cuttings to water during propagation is an essential first step in reducing the transmission of trunk diseases in propagation.

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Literature cited


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