HULL ROT OF ALMOND (AL16005)

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INTRODUCTION

Hull rot is a major disease affecting almond productivity. A recent industry-wide disease survey conducted across two seasons determined that approximately 70 per cent of Nonpareil is affected by hull rot in Australian orchards (Wiechel et al. 2020).

Hull rot causes direct loss of yield due to infected rotten nuts and downgrading of in-shell nuts, but it also reduces future yield due to twig dieback and loss of fruiting wood. In California, hull rot is mainly caused by two common fungi, *Rhizopus stolonifer* and *Aspergillus niger,* with *A. niger* more prevalent in the hotter regions (Michailides, pers. comm). These fungi look similar, i.e. fluffy and black, and a hand lens or a microscope is required to tell them apart. In Australia, hull rot is primarily caused by *Rhizopus stolonifer*. While *M. fructicola* and *A. niger* have been occasionally observed on almond hulls in Australian orchards they are not a major cause of hull rot.

Identification and symptoms

Hulls become susceptible to infection shortly after hull split with the early stages of split, B2-B3 (deep V stage), being most vulnerable (Figure 1). *Rhizopus stolonifer* is unable to penetrate the sealed hull but once hull split occurs, it can gain access to the moist inner surface which is an ideal environment for it to grow.

Figure 1 *Early hull split, when nuts are reported to be most susceptible to infection.*

Once inside the hull, the fungus grows on the inside surface of the hull resulting in a slight shriveling of the hull around the split.

If the weather is wet the fungus produces masses of dark black/grey spores which becomes visible within a few days (Figure 2).

Figure 2 *Shriveling of hull and black sporulation of Rhizopus stolonifer infection beginning inside the split hull. In humid conditions all surfaces of the nut may be covered with sporulating fungus.*

Infection is usually accompanied by spur death and twig dieback known as hull rot “strikes”. The first noticeable sign may be bunches of dried leaves. These usually remain pale green and may initially be quite hard to spot if infection levels are low (Figure 3). Severe infection can cause dieback of the whole stem with each spur along it infected.

Spur death and twig dieback is caused by acid by-products of the fungus which are translocated through the vascular traces and kill the plant tissues (Mirocha *et al.* 1961). Infection of older nuts, where the hull has begun to abscise, is less likely to lead to twig death due to the weakened connection between the nut and the twig, reducing translocation of the acid (Teviotdale *et al.* 1996). The recent industry-wide disease surveys found that 63% of hull rot in Nonpareil was associated with strikes.

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Figure 3 *The first noticeable sign may be bunches of dried leaves. These usually remain pale green and may initially be quite hard to spot if infection levels are low. Severe infection can cause dieback of the whole stem with each spur along it infected.*

Where it comes from

Rhizopus stolonifer is one of the most common fungi worldwide. It is found in all environments, in soil and on decomposing organic matter such as leaf litter. When the environment is conducive to fungal growth (i.e. mild to warm temperatures plus moisture), spore production in the orchard is prolific, the spores become airborne and are spread easily. Mummies (shrivelled nuts left in the tree from the previous season) have been assumed to be a major source of inoculum, but the data from our field trials does not support this. Less than 30 per cent of mummies produced inoculum when placed in ideal laboratory conditions, and there has been no correlation between mummies per tree and subsequent hull rot development.

Similarly, there has been an assumption that hull rot leads to the formation of mummies or “stick tights”, but again, the data from our field trials does not support this, with poor correlation between hull rot strikes and subsequent numbers of mummies (Figure 4).

Spores are dispersed by wind and rain splash into the canopy and onto split fruit. Insect pests may also carry spores into the split fruit. *Carpophilus* beetles are known to vector spores of the brown rot fungus within Australian stone fruit orchards (Holmes *et al.* 2011), and it is possible that they may spread *Rhizopus* spores in almond orchards.

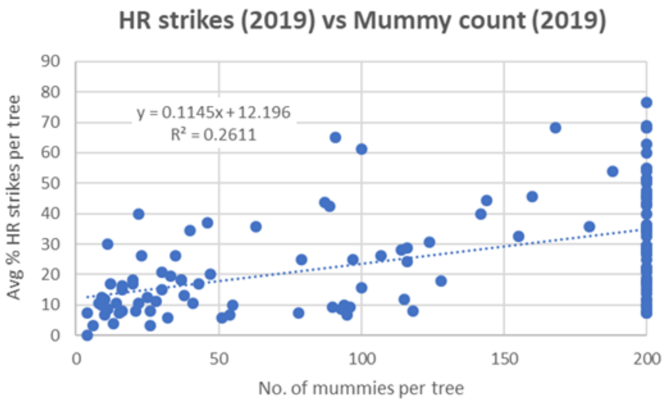

Figure 4. *Relationship between hull rot strikes and mummy numbers*

Favourable conditions

Rhizopus stolonifer requires high humidity and warm temperatures for growth and spore production. The optimum temperature range is 15-30°C, with poor growth below 10°C and above 30°C (Amiri *et al.* 2011; Pierson 1966).

Hull rot is strongly associated with rain events post-hull split. Statistical analysis of the industry-wide disease survey results found a highly significant correlation between hull rot incidence in an orchard with the amount and timing of regional rainfall in mid-late January.

Hull rot is often referred to as a good grower disease, being more prevalent where trees are well supplied with water and nutrients. While rainfall is out of our control, there has been much work done on irrigation practices and how they can be used to improve outcomes. Irrigation that promotes long periods of high humidity within the canopy is more favourable to hull rot development. Current trials in this project are investigating whether the use of imaging to identify areas of low, medium and high water stress in the orchard can predict hull rot incidence and severity.

Cultivar susceptibility

Susceptibility to hull rot varies among popular commercial almond varieties. The industry standard Nonpareil is among the most susceptible; common pollinisers such as Price and Wood Colony are moderately susceptible; while Carmel and Monterey are more resistant (Lightle *et al.* 2019). There is considerable effort put into the production of new breeding lines for Australian almonds (AL12015) with many new varieties in the pipeline. Recent assessments have identified that most of these new lines are less susceptible to hull rot than Nonpareil (Edwards 2020).

Control measures

Commonly reported methods of hull rot control include restrictions in water and nitrogen application and fungicides.

Californian research has demonstrated that imposing moisture stress during hull split reduced hull rot severity (Teviotdale et al. 2001). Additionally, restricting nitrogen leading up to hull split also reduced hull rot (Saa *et al.* 2016). Recent recommendations from California are -14 to -18 bars stem water potential (SWP) for two weeks, beginning just prior to hull split (*Niederholzer et al. 2020*) and sap nitrogen levels to be in the moderate range (2.2-2.5% N) at summer sampling (Doll 2020), with no further nitrogen applications after kernel development has completed.

Our trial investigating restricted water and nitrogen as a practical control measure in Australia demonstrated that when conditions prior to harvest were wet, restricted irrigation resulted in significantly fewer hull rot strikes. When conditions were dry hull rot severity was low anyway and any additional effect was not significant. We did not show that restricting nitrogen reduced hull rot severity (Faulkner *et a*l 2020).

Fungicides are an important part of a control program. Spraying at the right time is critical for good hull rot control with nuts most susceptible at early hull split but nut growth stage will vary across the orchard and may take two to three weeks for all nuts to reach this stage. It is recommended to start application before or as soon as the first nuts begin splitting. Good spray coverage is very important to reach the vulnerable split surfaces.

Typical spray volumes in Australian orchards vary but higher volumes and slower speeds give better coverage. Fungicide FRAC groups 3 (DMI) and 11 (QoL) and combinations of 11 with 3 and 7 (SDHI) are reported to give control in Californian orchards (Adaskaveg *et al.* 2017, University of California 2017). In Australia only two products from FRAC groups 3+11 are registered for hull rot suppression (APVMA Pubcris database). Alternative products such as alkali- and microbial-based products have also been suggested to provide hull rot control, but data on their efficacy has not been published.

Conclusion

Rhizopus stolonifer is the key pathogen causing hull rot in Australian almond orchards. It is a very common fungus and is favoured by high humidity, warm temperatures and January rainfall. Contrary to popular opinion, we did not find a correlation between hull rot and mummies. Early hull split is the most susceptible stage for pathogen infection. Once inside, the fungus colonises the inner surface of the hull and produces acid by-products which cause spur death.

Effective control measures are still under development. Protective sprays should be applied at early hull split to prevent the fungus colonising the fruit. Targeted application of water stress reduces disease severity when conditions are favourable. If rain events occur in January after hull split, consider whether early harvest is a practical option.

Future work will continue to investigate the effect of water stress on hull rot development, as well as gaining more insight into microclimatic effects on the infection process, assessing the susceptibility of root stocks and new varieties, and assessing alternative treatments.

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For further information about the “Integrated disease management program for the Australian almond industry (AL16005)” project led by Agriculture Victoria please visit

https://www.horticulture.com.au/growers/help-your-business-grow/research-reports-publications-fact-sheets-and-more/al16005/

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