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# Boosting Rambutan Productivity through Improvements in Fruit Set

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by James Drinnan and Mark Traynor

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# Foreword

The rambutan (*Nephelium lappaceum*) is a tropical, evergreen tree and a member of the Sapindaceae family, closely related to lychee and longan. It is native to the humid, tropical regions of Malaysia and Indonesia where the climate is relatively predictable and production fairly consistent. In Australian growing conditions, production has been poor and inconsistent from season to season. Poor fruit set due to poor pollination, and excessive fruit drop during fruit development prior to maturity appear to be two of the major factors contributing to this problem. The combination of these factors has had a severe impact on industry productivity and its ability to meet market demand. This has limited the expansion of the industry.

The rambutan industry has highlighted these issues as key production constraints in their strategic plan.

The aims of this project were to determine if synthetic auxins could be used:

- to promote the development of male flowers to enhance pollination, fruit set and yields; and
- to reduce fruit drop in Australian rambutan orchards.

The results indicate producers could substantially increase yields by the strategic use of the synthetic auxin NAA to promote the development of male flowers and TPA to reduce fruit drop. In turn, this would have a positive effect on the economic viability of the industry.

This project was funded from RIRDC Core Funds, which are provided by the Australian Government.

This report is an addition to RIRDC's diverse range of over 2000 research publications and it forms part of our New Plant Products R&D program, which aims to facilitate the development of new industries based on plants or plant products that have commercial potential for Australia.

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**Craig Burns**
Managing Director
Rural Industries Research and Development Corporation

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# Executive Summary

## What the report is about

This report investigates solutions to two serious production issues highlighted in the Australian Rambutan Growers' strategic plan; namely poor fruit set and excessive fruit drop. The combination of these two factors has contributed towards poor and inconsistent production from season to season reducing the economic viability of the industry. This has limited the expansion and growth of the industry. Variable production from year to year has also created problems in market development.

## Who the report is targeted at

The rambutan industry has highlighted the issues of poor fruit set and excessive fruit drop as key production constraints in their strategic plan. The research findings from this project are relevant to all Australian producers, as well as horticultural researchers and extension officers in Australia and overseas.

## Where are the relevant industries located in Australia?

Rambutans have been commercially produced in Australia since the 1970s. Today, production is estimated at around 750 tonnes worth about $4-5m. There are approximately 40 producers with a total of 25000 trees in production. Fruit is marketed domestically (70-90%) and exported (10-30%). The industry is located in north Queensland on the coast around Cairns (Cooktown to Tully, 16°S-17°S) and in the north of the Northern Territory around Darwin (12°S). The research findings from this project are likely to benefit all Australian producers.

## Background

The rambutan (*Nephelium lappaceum*) is native to the humid, tropical regions of Malaysia and Indonesia. In these areas, where the climate is reasonably predictable, production is reasonably reliable. When it is grown outside these climatic conditions, for example in Australia, production has been poorer and much more inconsistent. Two factors known to contribute toward this problem are poor fruit set due to poor pollination and excessive fruit drop.

The problem of poor pollination seems to be related to the lack of male flowers produced, especially in early flowering orchards when temperatures are low. This problem has been observed both in Australian production areas and in Hawaii. Overseas research and some preliminary work here has indicated that the synthetic auxin NAA applied as a foliar spray to developing panicles can induce the development of male flowers; however, no assessment of the impact of NAA application on production has been conducted.

Following successful fruit set rambutan yields can still suffer if fruit drop is excessive. Mid to late season fruit drop has been a problem in some orchards in some seasons, particularly in north Queensland. Little work has been conducted in this area here or overseas. To help understand the possible causes a literature search on the mechanisms of fruit drop was conducted. Using information from the literature search some preliminary trials using synthetic auxins to reduce fruit drop were conducted.

## Aims/objectives

- Determine the ideal rates and timings of the synthetic auxin NAA to promote the production of male flowers to improve pollination, fruit set and yields.

- Use the efficacy and residue data collected in this project to apply for registration of NAA for use in rambutan.

- Gain a better understanding of the factors and mechanisms involved in the mid to late season fruit drop often observed by conducting a literature review and some preliminary trial work.

## Methods used

Trials were conducted in Queensland and the Northern Territory across a range of varieties to determine the ideal rates and timings of NAA application to promote the development of male flowers to improve pollination and increase yields.

A literature review was conducted on the mechanisms behind fruit drop in rambutan and related species. With this understanding, preliminary trials were conducted to investigate if the synthetic auxin 3,5,6-TPA could be used as a foliar spray to counteract fruit drop.

## Results/key findings

Results indicate that a 40ppm foliar spray of NAA applied to developing flowers can promote the development of male flowers, which can significantly improve pollination, fruit set and yields in all the rambutan varieties studied. Up to ten fold increases in yield (or 15kg/tree) were recorded. An application for registration has been submitted to the APVMA. It is recommended that growers spray one in 15 or one per 2m$^2$ of flowering panicles evenly within trees at two-week intervals during the flowering period. Selecting panicles higher in the canopy and on the windward side of the trees and orchard will help to maximise the distribution of pollen by wind, insects and gravity.

The literature review on the mechanisms of fruit drop indicated that fruit drop in rambutan is probably controlled by a balance of the growth regulators auxin and ethylene. In other crops (e.g. lychee, a closely related species) applications of synthetic auxins have been used to reduce fruit drop. The results from the preliminary trials in this project indicate that 3,5,6-TPA can be used at 50ppm as a foliar spray on fruit 20-25mm in length to reduce fruit drop. Reductions in fruit drop of up to 25%, equivalent to a 60% increase in yield, were recorded.

If growers adopted these two practices, yields could be increased significantly, increasing the economic viability of this industry. Improved and more consistent yields would also help with market development.

## Implications for relevant stakeholders

### *Industry*

The project has developed two management strategies that can be used by the industry to improve their production.

### *Communities*

Rambutans are grown in the tropical regions of north Queensland and the Northern Territory. They require high labour inputs during harvesting, packaging and marketing. Improving the economic viability of the industry will ensure its growth and expansion, improving the economic outlook for the rural communities in which they are located via employment opportunities and increased demand for services.

### *Policy makers*

Rambutan production is an important part of horticultural production in northern Australia. Although small, supporting the industry contributes to the economic diversity of the horticultural industry and regional employment opportunities.

## Recommendations

The results from this research suggest Australia rambutan growers trial the use of NAA – once registered – on their varieties and in their growing conditions to improve pollination, fruit set and crop yields. In addition, growers could trial the use of 3,5,6-TPA to reduce fruit drop. Further efficacy and residue data is required for registration of 3,5,6-TPA. Guidelines on rates, timings and methods of application are given in this report.

# Introduction

The rambutan (*Nephelium lappaceum*) is a tropical, evergreen tree and a member of the Sapindaceae family, closely related to lychee and longan. It is native to the humid, tropical regions of Malaysia and Indonesia. Rambutan is extensively cultivated in Indonesia, the Philippines, Thailand and Borneo. In these tropical environments, where temperatures and rainfall patterns are quite predictable, production is usually good and reliable from year to year. However, in environments which are different to its natural environment (e.g. in Australia and Hawaii), production tends to be poorer and quite erratic from year to year.

Rambutans were first introduced into Australia in the 1930s and commercial production started in the 1970s. The main commercial varieties grown in Australia today are R9, R134, R156, R162, R167, Binjai, Jitlee and Rongrien. Production in Australia is confined to the tropical north coast of Queensland between Cooktown and Tully (17-18°S) and in the Northern Territory around Darwin (12°S). Australia now produces around 500 tonnes of rambutan per annum valued at around $4 million; however, this is highly variable from year to year, ranging from 300 tonnes to 800 tonnes depending on the season. The erratic production is caused by climatic variations from year to year causing poor and erratic flowering, poor pollination and fruit set and occasionally excessive fruit drop.

Rambutans flower primarily in response to water stress and, to a lesser extent, cool temperatures. The level of flowering is usually related to the duration and the severity of the water stress period (Nakason and Paull 1998). In Australia flowering usually occurs once per year during the dry season, from June to November. In the Northern Territory, flowering mostly occurs from June to August and in north Queensland from August to November. If the flowering stimulus is weak (e.g. insufficient water stressing, as quite often occurs in north Queensland) partial flowerings may occur and in these cases trees may flower again later. In the Northern Territory, which has a more distinct wet/dry season, flowering tends to be more intense and synchronised.

Observations in rambutan orchards in Australia have indicated that, as well as the level of flowering, the success of fruit set and fruit development and the severity of fruit drop can be important factors in determining final yields. Poor fruit set and fruit development (development of small parthenocarpic fruits that lack an aril) has been a common problem in many orchards in Australia. Observations in affected orchards indicate that this problem seems to be related to poor pollination. Poor pollination could be due to a lack of pollinating insects; however, in most cases it seems to be related to a lack of pollen or male flowers. During rambutan flowering three types of flowers are produced – staminate male flowers, hermaphroditic female flowers where the stamens do not fully develop and hermaphroditic male flowers where only the male parts of the flower fully develop.

In Australian orchards either none or very few male flowers are produced in the panicles of the cultivars grown, especially when flowering occurs early in the season. Temperature appears to play an important role; when temperatures are lower than optimum, flowers develop only as female and as temperatures increase some male flowers do start to be produced, although still in very small numbers. Poor fruit set and small parthenocarpic fruit (bally fruit), presumably caused by poor pollination, have been observed in both north Queensland and Northern Territory orchards and this has caused serious yield losses. Similar observations have been made in rambutan orchards in Hawaii and Thailand. In these two countries the synthetic auxin naphthalene acetic acid (NAA) (a plant growth regulator) has been used as a foliar spray to induce male flowering (Kawabata *et al.* 2004; Salakpetch 2000). By spraying developing panicles at the correct stage of development florets can be induced to open as male flowers. In this way the supply of pollen can be improved and fruit set and development can be enhanced. Preliminary trials in Australia (Diczbalis and Drinnan 2007) with NAA were encouraging with the production of male flowers; however, in all these studies no assessment of the impact of NAA treatments on yields were conducted.

One of the aims of this project was to determine the ideal concentrations and timings of NAA application for our varieties and to collect efficacy, residue and yield data to allow registration of NAA in Australia.

Following successful flowering, fruit set and early fruit development yields in rambutan orchards in Australia can still suffer if fruit drop is excessive. Mid to late season fruit drop has been a problem in some orchards in some seasons, particularly in north Queensland. Again, it appears to be weather related, with periods of very overcast, humid, wet weather contributing to the problem. Little work has been conducted in this area here or overseas. To help understand the causes of excessive fruit drop a literature search on the mechanisms behind fruit drop in rambutans and related species was conducted. Using the information from the literature search, some preliminary trials on reducing fruit drop using plant growth regulators were conducted.

# Objectives

- Determine the ideal rates and timings of the synthetic auxin NAA to promote the production of male flowers to improve pollination, fruit set and yields.
- Use the efficacy and residue data collected in this project to apply for registration of NAA for use in rambutan.
- Gain a better understanding of the factors and mechanisms involved in mid to late season fruit drop often observed by conducting a literature review and some preliminary trial work.

# Methodology

During 2008 and 2009 research trials were conducted on rambutan orchards in north Queensland between Cairns and just south of Tully (16-17°S) and in the Northern Territory around Darwin and Berry Springs (12°S).  A range of commercially grown varieties were used, including R134, R156, R162, R167, Binjai, Jitlee and Rongrien.  Where varieties could be identified and there were sufficient numbers of trees trials were conducted on individual varieties; however, in many of the older orchards individual varieties could not be identified or were mixed planted and in these cases treatments were conducted across varieties.

Trees were 6-20 years old and ranged in size from 2m × 2m to 5m × 5m.  Trees were planted in rows 6-10m apart and trees were spaced at 6-10m giving tree densities of 100-250 plants/ha.  Orchards were protected from birds and bats with either permanent or temporary netting.  All orchards were irrigated, fertilised and trees kept free of pests and diseases and in a healthy productive state.

# 1. Naphthalene Acetic Acid Trials

## 1.1 Introduction

Poor fruit set and low yield has been a problem in Australian rambutan orchards, especially in seasons where flowering is early. Observations have indicated that very few male flowers are produced in these early flowering panicles and that this leads to poor pollination because of a lack of pollen. Similar observations have also been made in Hawaii and parts of Thailand (Kawabata *et al.* 2004; Salakpetch 2000). Rambutans are known to naturally have a very low percentage of male flowers, often below 1% and sometimes below 0.05% (Valmayor *et al.* 1970). When rambutans are cultivated in areas outside their natural environment with cooler than ideal temperatures this problem is further exacerbated. When pollination is poor fruit set is poor and it can lead to the development of deformed parthenocarpic fruit, which fail to develop properly reducing yields. Rambutan pollen is known to have good viability, remaining viable for a long time and the stigma on female flowers remains receptive for up to 48 hours, so when pollen is available pollination is usually successful.

Rambutans produce three types of flowers – male, hermaphrodite female and hermaphrodite male. Pollen is produced by the male and hermaphrodite male flowers and fruit is only set in the hermaphrodite female flowers.

NAA has been used in Thailand and Hawaii to increase male flower development to aid pollination (Kawabata *et al.* 2004; Salakpetch 2000). Application of NAA to developing panicles during early anthesis was able to induce the development of hermaphrodite male flowers. Experiments in Hawaii (Kawabata *et al.* 2004), Thailand (Salakpetch 2000) and preliminary trial work here in Australia (Diczbalis and Drinnan 2007) have shown that NAA applied at 40-90ppm as a foliar spray is able to stimulate the development of male flowers. With the increase in pollen available it is assumed pollination should be better and yields increase; however, the yield benefits of doing these treatments has not been determined.

Studies have indicated that self pollination is less successful than cross pollination (Sarip *et al.* 2007) so having male and female flowers in trees across an orchard simultaneously, as should occur with the use of NAA, is likely to have a further positive effect on improving pollination and fruit set.

The objective of this research was to determine if NAA could be used in Australian climatic conditions and on the varieties grown to improve crop yields. Efficacy and residue data was also collected to allow an application for registration of NAA use in rambutan to be submitted.

## 1.2 Materials and methods

During May to July, trees were observed weekly for signs of flowering. When sufficient trees with reasonable levels of early flowering were identified trials commenced. In north Queensland flowering started in July-August in 2008 and August-November in 2009. In the Northern Territory flowering started in June in 2008 and 2009. Several separate trials were conducted across a range of varieties (R134, R156, R162, R167, Binjai, Jitlee and Rongrien).

In all the trials early flowering trees (12-26) were identified, marked and split into two groups – those treated with NAA and those left as untreated controls. The two groups of trees were separated within the orchard as much as possible to reduce the chance of pollen moving from the treated trees to the untreated trees by wind or insects. Trees were mostly separated by at least 50m and/or several rows of trees.

On the treated trees 3-12 panicles (depending on the tree size and the level of flowering) were tagged and sprayed with 40ppm (2ml/L) NAA (naphthalene acetic acid) "Stop Drop" plus 0.1% Kendral 600 wetter (manufactured by Kendon Chemicals Pty Ltd). The rate of 40ppm was chosen after referring to the preliminary work done by Diczbalis and Drinnan (2007) in Australia, Salakpetch (2000) in Thailand and Kawabata *et al.* (2004) in Hawaii. In these studies, it was concluded that rates above 90ppm can damage (burn) the flowers and rates below 20ppm are less effective. By using the low rate of 40ppm, it was hoped that the flowers that did not respond to the NAA on the first application would not be damaged and could be used on subsequent applications.

Panicles were sprayed with NAA using a hand sprayer until runoff. Spraying occurred late in the afternoon to reduce the chance of evaporative losses and improve the absorption of the NAA. Panicles were first sprayed at the start of anthesis or when the pistil could be seen protruding from the closed florets (Figure 1). After 10-14 days the same panicles were sprayed again if there were still unopened flowers at the correct stage of development. If there were no flowers left to open, new panicles were tagged and sprayed on subsequent applications. This continued until all the flowering on the trees had finished – usually 3-4 applications (6-8 weeks). In deciding the number of panicles to treat per tree, about one in 10-15 panicles, or one per $2m^2$ of the flowering canopy were treated. Panicles were chosen in the upper part of the canopy, evenly spaced amongst the other non-treated panicles to aid pollination by wind or insect.

**Figure 1. The ideal stage to apply NAA is when flowers have just started to open or when the pistil is seen just protruding from the closed florets (inset).**

Flowering and fruit set was observed in the trees at weekly intervals and yield data collected from individual trees. Canopy size and the percent of the canopy flowering was recorded where tree size or the level of flowering was variable across trial trees so that the yield per area of the canopy flowering could be calculated. Where trial trees were uniform in size and level of flowering the yield per tree is presented. Trees were harvested 4-5 months after flowering at 1-2 week intervals. A sample of fruit was collected from some of the trials for fruit quality assessment (size, weight, seed development) and residue testing (Agrisearch Analytical Pty Ltd).

The maximum and minimum temperatures at centres close to the trial sites were sourced from the Bureau of Meteorology.

## 1.3 Results and discussion

### 1.3.1 Flowering and fruit set

In all trials in both states and on all varieties studied the NAA applications stimulated the production of male and hermaphrodite male flowers on treated panicles within 7-10 days of application (Figure 2). Closed florets with the pistil protruding developed into hermaphrodite male flowers. Flowers slightly less developed opened as male flowers (Figure 2). The flowers already open at the time of application remained female and were generally damaged or burnt by the NAA sprays. The florets at much earlier stages of development continued to develop normally, opening as female flowers unless treated with NAA on a subsequent application.

**Figure 2. Male flowers are seen on panicles 7-10 days after spraying with NAA.**

Observations of the flowers throughout the orchard on panicles not sprayed with NAA indicated that there were either no male flowers present up until September in the Northern Territory and up until October in Queensland or the numbers were so small that they were not detected (Figure 3). After this time small numbers of male flowers were observed, which seemed to correlate well with increasing temperatures (Figures 7 and 8). Small numbers of male flowers were regularly seen in trees flowering later in the season, during summer. Fruit set and cropping is usually reasonable on these later flowering trees.

**Figure 3.** **Rambutans produce predominantly female flowers, especially when they flower early in the season when temperatures are low.**

In all the trees treated with NAA a significant increase in the number of fruit set within the first few weeks of male flowers being present was evident, especially on the panicles in close proximity to the treated panicles (Figure 4). Presumably this was due to better pollination. In most cases, this led to an increase in yield. No fruit set or fruit development was observed on treated panicles (Figure 4). This was expected because any open female flowers at the time of spraying were damaged or burnt by the NAA and any subsequent flowering was only male. This indicates that when using NAA choosing the correct number of panicles to treat will be a compromise between getting a good number of male flowers, and hence pollen supply evenly distributed throughout the trees and orchard to ensure the highest likelihood of pollination, and not treating too many panicles that it starts to reduce yields by limiting the number of panicle able to crop. The number of panicles chosen to be treated in these trials – 3-12/tree depending on tree size (2m × 2m – 5m × 5m), or one in every 10-15 panicles, or one panicle per $2m^2$ of the flowering canopy – resulted in significantly increased yields in most trials and suggests this number is a good starting point.

The location of treated panicles within the trees or the orchard is also a key consideration. Ideally, they should be chosen amongst other panicles and higher in the canopy as these will be more exposed to wind and insects for disseminating the pollen. From higher in the canopy, pollen can also fall through the tree onto other panicles. These upper panicles are usually more difficult and expensive to harvest and more prone to bird, bat and net damage so reducing the yield (by treating with NAA) on these panicles will have a lesser effect on the overall yield than treating other panicles. Panicles should also be chosen on the upwind side of trees or the orchard so that the prevailing wind will help to distribute the pollen.

**Figure 4. Good fruit set is observed on panicles (foreground) in close proximity to the NAA treated panicles (background), which fail to set fruit.**

## 1.3.2 Yields

### 2008 Northern Territory trials

The results from the 2008 trials in the Northern Territory are shown in Table 1. Yields in trees treated with NAA increased over the control trees in all three trials. In Trial 1 the yield per $m^2$ of the canopy increased by 12%, equivalent to about 3kg/tree based on the average tree size in this trial. In Trials 2 and 3, which were conducted on a different orchard on single varieties and smaller trees, yield increases of 3.5kg and 5.9kg/tree (equivalent to a 48% and 140% increase) were found.

The smaller yield increases in Trial 1 may be explained by the fact that this trial was conducted on a mixed variety block (Binjai, Jitlee, R167, R134) with control and treated trees having roughly the same mix of varieties. Trees were mixed ages and sizes and the orchard was under permanent netting. Treated and control trees could not be separated from each other as well as in Trials 2 and 3 because of space limitations. There were also some seedling trees (which had male flowers) planted in the netted area, although these were some distance from the control trees. Beehives in the netting structure were also used by the grower to improve pollination. These factors may have meant some pollen from either the treated trees or the seedling trees may have inadvertently caused some pollination in the control trees. The reasonably high yields in control trees in this trial suggest that this was the case.

**Table 1.** **Effect of NAA panicle sprays on tree yields on trials in 2008 in the Northern Territory.**

***Trial 1: Trees 6-20 years old; 2m × 2m – 5m × 5m in size; varieties R134, R167, Binjai and Jitlee. Data is the average of nine trees. Yield significantly different (P=0.05).***

| Control | | | NAA | | |
|---|---|---|---|---|---|
| Yield (kg/tree) | Tree size ($m^2$) | Yield/$m^2$ of canopy (kg/$m^2$) | Yield (kg/tree) | Tree size ($m^2$) | Yield/$m^2$ of canopy (kg/$m^2$) |
| 17.4 | 8.1 | 2.6 | 23.2 | 10.1 | 2.9 |

***Trials 2 & 3: Trees 7 years old; 2m × 3m in size. Data is the average of eight trees. Yields significantly different (P=0.05).***

| Variety | Control | NAA |
|---|---|---|
| | Yield (kg/tree) | |
| Binjai | 4.2 | 10.1 |
| R167 | 7.2 | 10.7 |

In Trials 2 and 3 single varieties (Binjai, R167) were used. In this orchard, the trees were uniform in age, size and level of flowering so the yields could be expressed on a per tree basis. Because of the size of the planting area and the age and size of the trees treated and control trees could be well separated. There were also no seedling trees in this orchard. The orchard was not permanently netted and bees were not used to improve pollination. All these factors would have reduced the chance of pollen moving from the treated trees to the control trees. Therefore, the results from Trials 2 and 3 are more likely to accurately demonstrate the effect of NAA.

The fruit set, fruit development and cropping on control trees in Trials 2 and 3 indicates that some pollination is occurring despite observations indicating that there were no male flowers present in these early flowerings. Obviously some pollen was present in these trees – this may have come from male flowers which developed in the trees in later flowerings subsequent to our observations, or very small numbers of male flowers may have been present in the orchard that were not detected during flower observations, or pollen may have moved inadvertently from treated trees to control trees by wind or insects which appears to have been the case in Trial 1.

## 2008 north Queensland trials

The results from the trials conducted in north Queensland in 2008 (Table 2) were quite variable compared to those in the Northern Territory. At the Murray and Tully Valley sites trees failed to crop from the early flowerings, with or without the use of NAA, whereas yields did improve (by a similar amount as trials in the Northern Territory) in the trial conducted at the Cairns site. Early observations indicated fruit set increased on the NAA treated trees at all three sites; however, at the Murray and Tully Valley sites the fruit failed to develop normally on treated trees and remained as small (5-10mm), parthenocarpic fruit with no seed development, as was the case in the control trees (Figures 5 and 6). The cool minimum temperatures (6-12°C) (Figure 7) experienced at these two sites following flowering and pollination are believed to have caused either unsuccessful fertilisation or abortion of the developing embryo after fertilisation. At the Cairns trial site where minimum temperatures were warmer (10-17°C) (Figure 1) most of the early fruit set in the treated trees did develop normally and yields were significantly higher than in control trees (Table 2).

**Table 2.** **Effect of NAA panicle sprays on fruit set and tree yields on early flowering trees during 2008 in north Queensland. At all sites a range of cultivars were treated, including R134, R156, R162, R167, Binjai and Jitlee. Results are the average of seven trees.**

| Trial Site | Control | | NAA | |
|---|---|---|---|---|
| | Fruit Set | Yield (kg/tree) | Fruit Set | Yield (kg/tree) |
| Murray Valley Site | Poor | 0 | Good | 0 |
| Tully Valley Site | Poor | 0 | Good | 0 |
| Cairns Site | Poor | 1.9 | Good | 5.1 |

**Figure 5.** **Small, undeveloped fruit are caused by poor pollination or fertilisation. They were observed mostly on control trees where pollination was poor, but also on treated trees when temperatures were low (6-12°C) following pollination, possibly interfering with fertilisation.**

**Figure 6.** **Poor pollination and fertilisation leads to the development of small (5-10mm), parthenocarpic fruit with no seed development and little aril.**

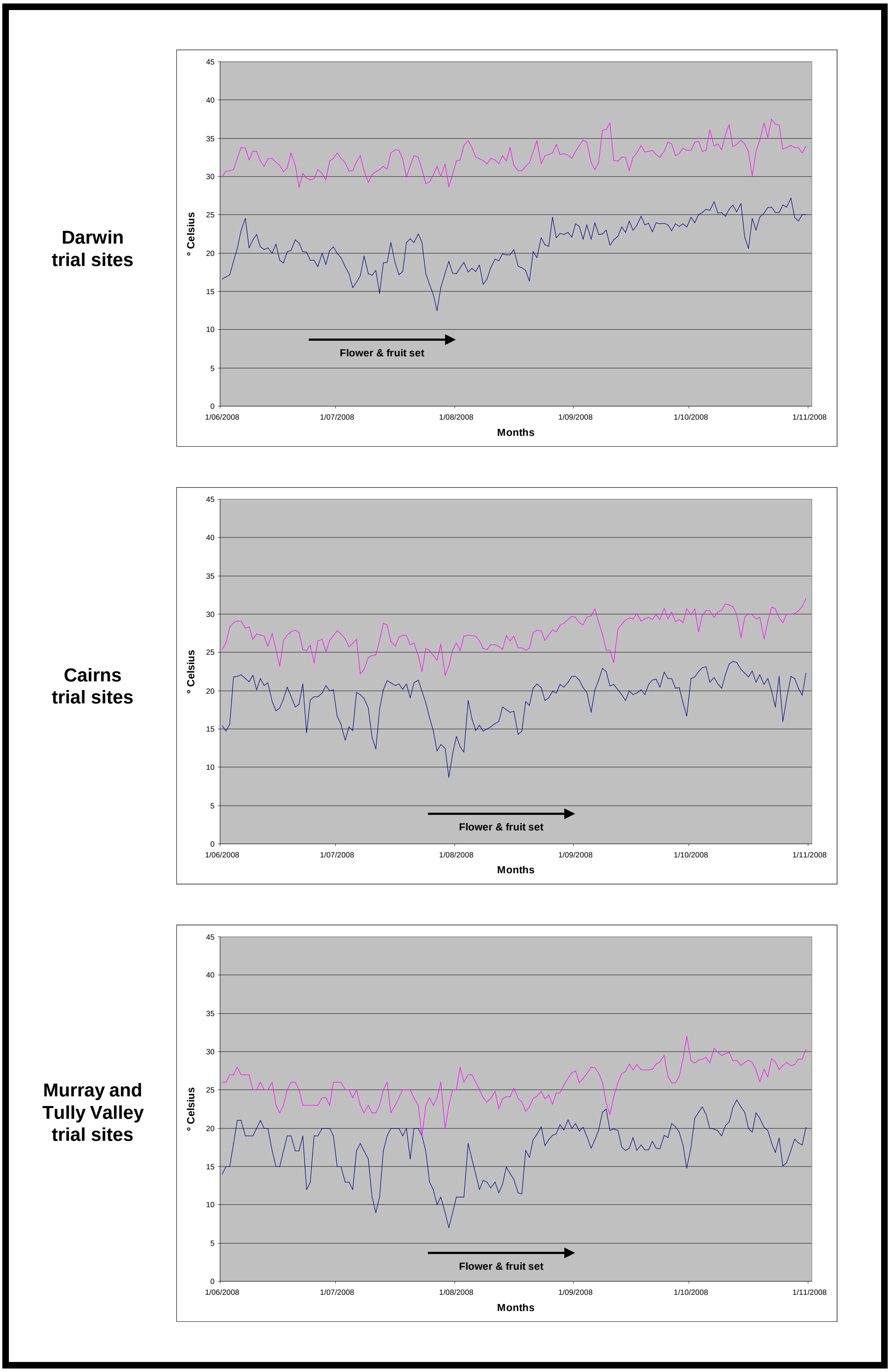


**Figure 7. Daily maximum and minimum temperatures during flowering and fruit development at weather stations close to trial sites in 2008.**

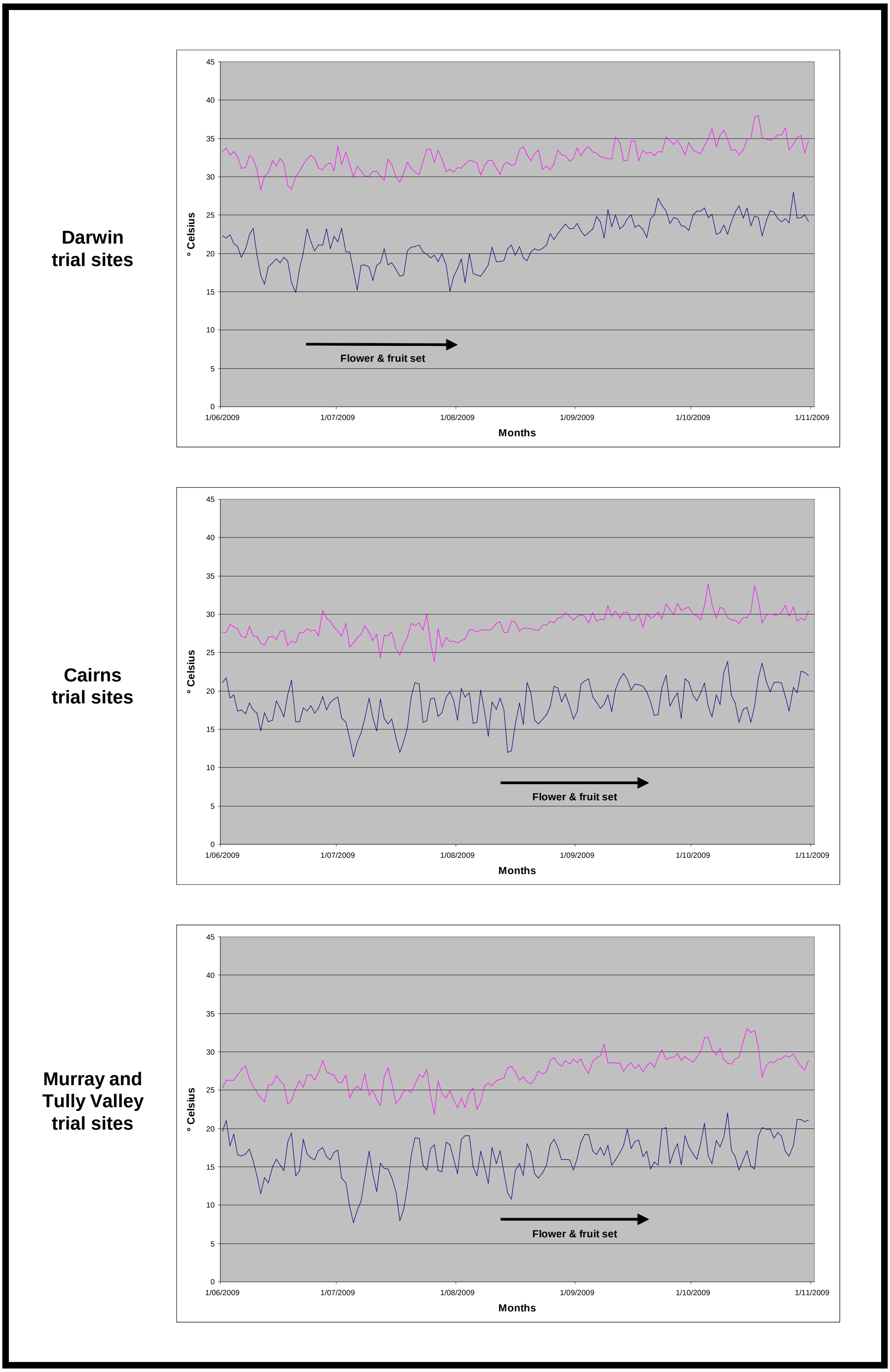


**Figure 8. Daily maximum and minimum temperatures during flowering and fruit development at weather stations close to trial sites in 2009.**

The increase in yields following NAA use in the Northern Territory trials in 2008 and 2009 and the Queensland trials during 2009 when minimum temperatures were warmer (Figures 7 and 8) also suggests that minimum temperatures following NAA treatment are critical for the success of the NAA treatments. This finding has important implications for the use of NAA in locations that experience low minimum temperatures during early flowering. It suggests that NAA will be most useful in locations or in seasons where minimum temperatures are not too low (>12°C). These results indicate that successful cropping from early flowering in rambutan in Australian production areas relies on two factors – the presence of male flowers to ensure a pollen source for pollination and warm minimum temperatures following flowering to ensure successful fertilisation, embryo and fruit growth. Unless both of these conditions are met no fruit will develop. At locations or in seasons where minimum temperatures are often below 12°C following flowering it may not be possible to get successful cropping from these early flowerings even with the use of NAA, as was the case at the Murray and Tully Valley sites in 2008.

Successful fruit development relies on pollination and fertilisation. If pollination occurs without fertilisation there is sometimes enough stimulus from plant growth regulators (produced in response to pollination) that the ovary starts developing into a fruit; however, the stimulus is soon exhausted without any new signals from a developing seed/embryo and fruit development ceases (Figure 6). This appears to be the case when low temperatures follow pollination. In normal fruit development, after fertilisation the developing embryo or seed produce plant growth regulators that stimulate fruit growth (Figure 9).

**Figure 9. Tree with good fruit set and fruit development following NAA treatments to enhance pollination.**

## 2009 Northern Territory trials

The results from the trials conducted in the Northern Territory in 2009 are shown in Table 3. In all four trials yields significantly increased over control trees, with the NAA treated trees recording up to ten times (15kg/tree) the yield of the control trees. These significant yield increases again demonstrate the dramatic effect a lack of male flowers (pollen supply) can have on limiting the potential yielding capacity of early flowering rambutan trees growing in regions outside their natural environment. In these situations, low temperatures appear to inhibit the development of male flowers limiting pollination and fruit set (e.g. in north Queensland and the Northern Territory in Australia and in Hawaii).

**Table 3. Effect of NAA panicle sprays on tree yields on trials in 2009 in the Northern Territory.**

***Trial 1: Trees 8 years old; 2m × 3m in size. Data is the average of five trees. Yield significantly different (P=0.05).***

| Variety | Control | NAA |
|---|---|---|
| | Yield (kg/tree) | |
| Binjai | 2.6 | 5.1 |

***Trials 2, 3 and 4: Trees 9 years old; 3m × 3m in size. Data is the average of 7-8 trees. Yields significantly different (P=0.05).***

| Variety | Control | NAA |
|---|---|---|
| | Yield (kg/tree) | |
| Binjai | 6.9 | 17.0 |
| Jitlee | 1.8 | 17.6 |
| R134 | 1.7 | 14.3 |

The yield response of the different varieties studied in these and previous trials indicates that NAA is likely to have a significant positive effect on improving yields in all varieties. However, significant differences in the size of the response were observed between the varieties studied. The yield increase in the variety Binjai was very consistent between the three trials; around 2-2½ times the yield of the control trees. For the variety R167 the yield increase was around 1½ times and for R134 and Jitlee the increase was much larger at around eight and ten times. This indicates that the use of NAA may be even more critical in the varieties R134 and Jitlee compared to the varieties Binjai and R167 for improving pollination. There are a number of possible explanations for these differences:

### *The responsiveness of each of the varieties to NAA in inducing the development of male flowers*

Nagao (2004) and Kawabata *et al*. (2004) both found that some varieties produce a lot of male flowers and others much fewer when treated with NAA. They found that Jitlee produced the greatest number of male flowers followed by R134, then Binjai and the least sensitive was R167. Jitlee produced 80-100 male flowers per panicle compared to only 20-30 for the variety R167. Diczbalis and Drinnan (2007) also found the variety R134 very responsive to NAA, producing hundreds of male flowers per panicle. The size of the yield increases in these trials matches almost exactly the responsiveness of the varieties to NAA found by these researchers.

### *The difference in yielding capacity of the control (untreated) trees between varieties*

The yields of the treated trees at each of the sites were quite consistent and appeared to be related to the size of the trees and the level of flowering; however, the yield of the control trees was much more variable. It is possible that very small numbers of male flowers were produced naturally even in the early flowering panicles in the varieties Binjai and R167 allowing control trees in these varieties to produce some fruit. Therefore, the increase in yield with NAA applications was smaller than expected. In the varieties Jitlee and R134, the yields of the control trees were very low (perhaps because no male flowers are produced in early flowering panicles); therefore, the yield increases with NAA application in these varieties were very large.

*The difference in the ease of pollination and fruit set between varieties*

If pollination and fruit set were difficult or poor, control trees with little or no pollen and low rates of pollination and fruit set would have very low crops. Increasing the pollen supply using NAA in these situations may greatly improve the success of fruit set (this could be the case in the varieties Jitlee and R134). If pollination and fruit set occurs very easily then even small amounts of pollen (produced either by themselves or from other pollen sources) may be sufficient to get good pollination and fruit set and increasing the pollen supply may not improve yields to the same extent as when pollination and fruit set are difficult. This could be the case in the varieties Binjai and R167.

It is possible that all of these explanations contribute to the differences in the yield responses observed between these varieties.

### 2009 north Queensland trials

The results from the trials conducted in 2009 in north Queensland are shown in Table 4. Similar to the results in the Northern Territory in 2008 and 2009, spot spraying a small number of panicles with NAA increased yields by 25-84%, equivalent to 4-14 kg/tree based on the average tree size in these trials. During this year problems with poor fruit development and parthenocarpic fruit (Figure 6) at the Murray and Tully Valley sites were much smaller, presumably due to the warmer minimum temperatures during and after flowering in 2009 compared to those in 2008 (Figures 7 and 8).

**Table 4. Effect of NAA panicle sprays on tree yields on trials in 2009 in north Queensland.**

***Trial 1: Trees 9-15 years old; 3m × 4m – 5m × 5m in size; varieties R134 & R167. Data is the average of eight trees. Yield significantly different (P=0.05).***

| Control | | | NAA | | |
|---|---|---|---|---|---|
| Yield (kg/tree) | Tree size ($m^2$) | Yield/$m^2$ of canopy (kg/$m^2$) | Yield (kg/tree) | Tree size ($m^2$) | Yield/$m^2$ of canopy (kg/$m^2$) |
| 11.7 | 14.7 | 0.8 | 18.5 | 15.2 | 1.22 |

***Trial 2: Tully Valley site; trees 6-12 years old; 2m × 2m – 4m × 4m in size; variety Binjai. Data is the average of seven trees. Yield significantly different (P=0.05).***

| Control | | | NAA | | |
|---|---|---|---|---|---|
| Yield (kg/tree) | Tree size ($m^2$) | Yield/$m^2$ of canopy (kg/$m^2$) | Yield (kg/tree) | Tree size ($m^2$) | Yield/$m^2$ of canopy (kg/$m^2$) |
| 18.3 | 9.5 | 1.92 | 17.1 | 7.1 | 2.4 |

***Trial 3: Murray Valley site; trees 6-9 years old; 2m × 2m – 4m × 4m in size; varieties R134, R167, R156 & Binjai. Data is the average of 13 trees. Yield significantly different (P=0.05).***

| Control | | | NAA | | |
|---|---|---|---|---|---|
| Yield (kg/tree) | Tree size ($m^2$) | Yield/$m^2$ of canopy (kg/$m^2$) | Yield (kg/tree) | Tree size ($m^2$) | Yield/$m^2$ of canopy (kg/$m^2$) |
| 15.2 | 8.1 | 1.9 | 33.5 | 9.5 | 3.5 |

### 1.3.3 Fruit maturity, quality and residues

Fruit ripened about four months from flowering in the Northern Territory and five months from flowering in north Queensland. The pattern of fruit ripening across all the trials indicated that fruit generally matured at about the same time in the NAA treated trees as in the control trees. The patterns of fruit maturity in Trials 2 and 3 in 2008 in the Northern Territory that were similar to the results in the other trials are shown in Figure 10.

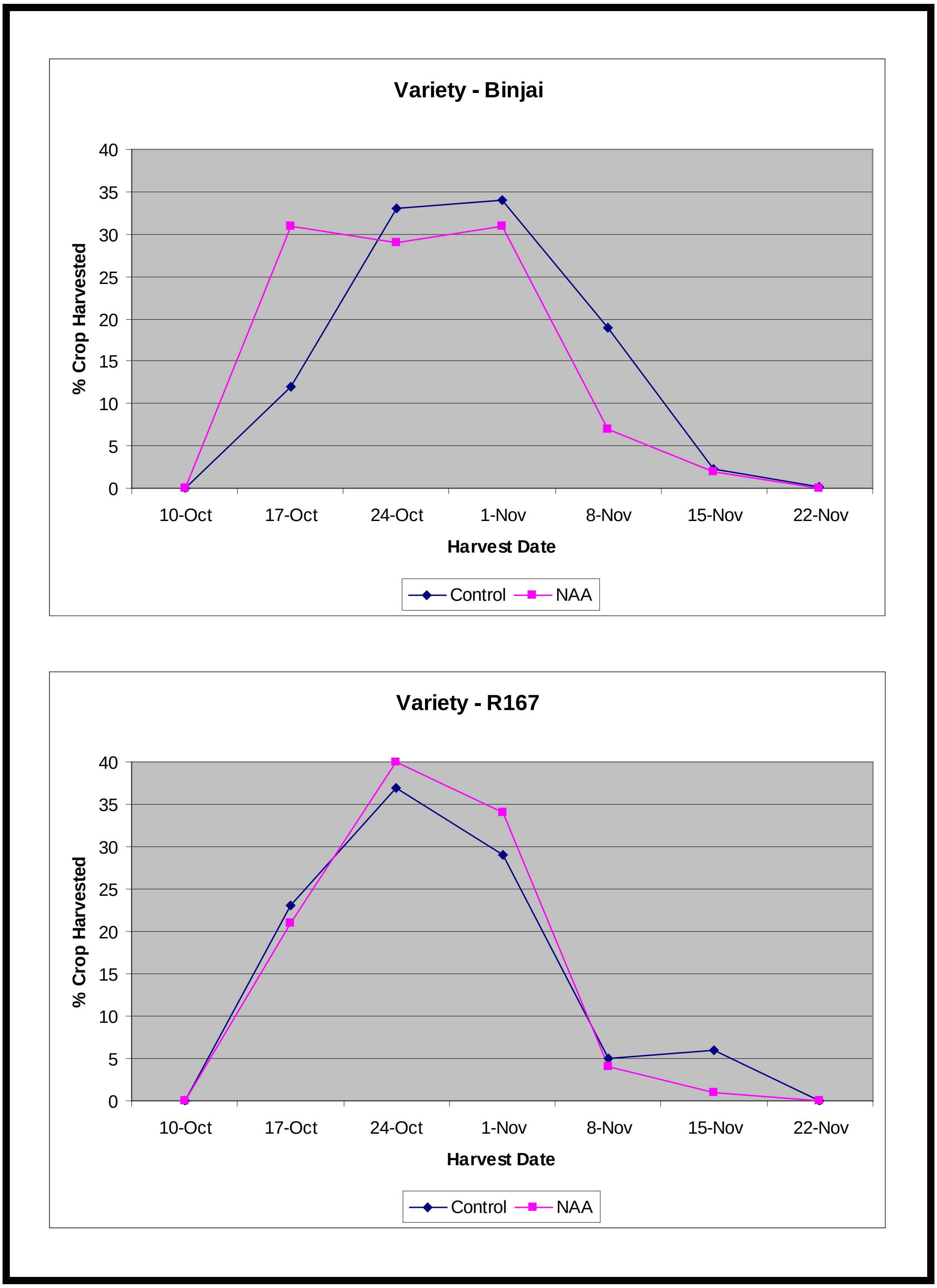


**Figure 10. Effect of NAA panicle sprays on the pattern of fruit maturity in 2008 in the Northern Territory.**

Fruit quality assessments indicated that there was no difference in size, weight or seed development between fruit from NAA treated trees and control trees. The fruit size in Trials 2, 3 and 4 in 2009 in the Northern Territory that were similar to the results in the other trials are shown in Table 5.

**Table 5. Effect of NAA panicle sprays on fruit weight on trials in 2009 in the Northern Territory. Data is the average of 50 fruit.**

| Variety | Control (g) | NAA (g) |
|---|---|---|
| Binjai | 32.8 | 31.6 |
| Jitlee | 26.4 | 27.6 |
| R134 | 33.6 | 34.0 |

The residue analysis of fruit collected from the treated and control trees showed that no NAA residues could be detected (Table 6). This was expected as the NAA is only applied to a very small proportion of the tree (3-12 panicles/tree) and the panicles treated did not set any fruit.

**Table 6. NAA residues in fruit collected from treated and untreated trees.**

| Sample | Residue in skin and flesh |
|---|---|
| NAA Treatment, 3 weeks before harvest | < LOD |
| NAA Treatment at harvest | < LOD |
| Control Treatment | < LOD |

LOD = Level of detection 0.02 mg/kg (Agrisearch Analytical Pty. Ltd.).

# 2. Literature Review – Fruit Drop

In most tree crops, there are many more fruit set than a tree is able to support to maturity. Fruit drop is the mechanism by which trees regulate their crop load so that they are able to support the developing fruit to maturity. The role of fruit drop is an important aspect in crop production because it affects the crop yield.

Fruit trees can be divided into three groups based on this crop load regulation. There are fruit crops that can suffer from over regulation (excessive fruit drop where too much fruit is shed) so that the crop load is often much less than the tree is able to support. Mango (Singh *et al.* 2005), lychee (Yuan and Huang 1988), avocado (Lovatt 1990) and macadamia (Trueman and Turnbull 1994) are examples where excessive fruit drop in some seasons and in some varieties can cause significant yield losses. The second group of fruit trees are considered to have a level of fruit drop that results in crop loads roughly in balance with what can be supported by the tree. Most of the citrus species fall into this group (Monselise *et al.* 1981). In the third group, the level of natural fruit drop is usually inadequate so that the trees tend to overcrop. In these cases, the tree is unable to support all the developing fruit to maturity leading to reduced fruit size, low sugar levels, poor fruit quality and often overall tree decline. Examples of these fruits are apple (Byers *et al.* 1991), peach (Bangerth 2000), coffee (Drinnan 1998) and longan (Diczbalis and Drinnan 2007). In these crops, flowering and fruit thinning treatments may be necessary to balance the crop load with the yield capacity of the tree.

Fruit drop in rambutan places it in the first group, where usually too much fruit is shed (particularly in some varieties and in some seasons) so that the crops are often less than the tree is able to support. Lim (1984) reported that up to 90% of fruit is shed between fruit set and harvest and that excessive fruit set can lead to heavy fruit drop. About 50% of the fruit drop occurred when fruit were half grown and this was aggravated by heavy rainfall and overcast conditions; this has also been the experience of growers on the wet tropical coast of north Queensland. Poor nutrition, high winds, low soil moisture and even systemic insecticides have also been linked to fruit drop. Watson (1985) found that rambutan trees have a good capacity to shed fruit from overcrowded panicles at the ¾ grown stage. Van Welzen *et al.* (1988) have also observed heavy fruit drop in rambutan. He notes that panicles have thousands of flowers and only a small percentage of these set fruit. At early fruit set, panicles may have 40-60 fruit and this gradually declines to 12-15 fruit over the 3½ to 5 months between fruit set and maturity. Poor nutrition, climatic and physiological factors can enhance the fruit drop.

In Australia, growers have observed fruit drop from early fruit set to just before maturity. Fruit drop from the ¾ grown stage to just before maturity has been responsible for the biggest crop losses. The mid to late maturity fruit drop appears to be related to climatic conditions during fruit filling. In north Queensland observations over a number of years suggests that heavy fruit drop tends to occur following periods of overcast wet weather and can result in losses of up to 60% of the total crop (Diczbalis and Drinnan 2007). Little or no research has been conducted on this problem. It is thought that fruit drop occurs because of plant stress brought on by a lack of radiation or water logging following prolonged wet, overcast conditions. These conditions presumably lead to a reduced supply of resources for the developing fruit due to reduced photosynthesis and nutrient uptake. The stress placed on the plant by these adverse weather conditions may also cause abscisic acid and ethylene levels in the plant to increase, which have been associated with fruit drop in other crops (Bangerth 2000).

The two main theories given for fruit drop in the literature are:

a) Insufficient resources within the tree leading to starvation of some fruit and abscission.

b) A regulatory hormonal mechanism by which the plant prioritises development of some fruit and shedding of others.

There is evidence in the literature that supports the theory of limited resources within the tree causing fruit drop (Goldschmidt and Koch 1996; Bustan *et al.* 1995; Wolstenholme *et al.* 1988). In avocado Lovett (1990) and Kalmar and Lahau (1976) found there is strong competition between vegetative growth and fruit growth and that fertilizing at this stage could result in excess vegetative growth at the expense of fruit growth. Pruning and the use of paclobutrazol (a growth suppressant) were able to reduce vegetative growth, which in turn reduced fruit drop and increased yields. Similar results have also been found by Cutting and Bower (1990) and Wolstenholme *et al.* (1988). Other research (Ruiz and Guardiola 1994; Guardiola *et al.* 1984; Trueman and Turnbull 1994; Abruzzese *et al.* 1995) reveals no link between carbohydrate limitation and fruit drop in apple, citrus, macadamia and peach respectively. The carbohydrate limitation theory also cannot explain why some fruit is shed yet others are held and why fruit drop tends to occur in waves during fruit development. It would appear that assimilate shortage is a secondary mechanism rather than a primary cause of fruitlet abscission.

The theory of a hormonally regulated fruit drop would appear to be the more likely mechanism. The hormonal regulation of fruit drop is explained by the changing balance of the plant growth regulators (auxin and ethylene) in the young fruit and the abscission zone. When young fruit is developing it usually produces high levels of auxins (particularly IAA) that move out of the fruit through the abscission zone towards the roots (basipolar transport) (Bangerth 2000). The flow of auxin through the abscission zone reduces its sensitivity to the growth regulator ethylene. If the level of auxin in the fruit or the flow of auxin through the abscission zone declines the sensitivity to ethylene increases. The ethylene stimulates hydrolytic enzyme production that causes cell walls to collapse and the abscission layer to form.

Small, slow growing fruit with few or no seeds and fruit that have poorly developed seed or embryos are particularly susceptible to fruit drop because the amount of auxin produced in these fruit is usually reduced; therefore, the flow of auxin out of the fruit is also reduced, which allows the ethylene to activate the hydrolytic enzymes in the abscission zone and cause fruit drop.

The other mechanism that regulates these hormonal interactions is the rate of flow of auxins at the junctions where two or more sources of auxins meet. In this case, the more dominant source or largest flow of auxin will exert an inhibitory effect on the auxin transport of the less dominant source. If the transport of auxin is sufficiently prevented, ethylene will activate the abscission zone and the less dominant source will be shed. The dominant sources of auxin may be from the first set fruit, the largest fruit or the fruit with the largest or most number of seeds, it could also be actively growing vegetative shoots, all of which produce large amounts of auxins that will lead to abscission of the less dominant sources (for example small fruit).

The role of auxins in fruit drop is supported by numerous reports that applications of auxins can reduce fruit drop. In lychee (a closely related species to rambutan), Liu (1986) found auxin levels fall dramatically at the time of fruit drop and this caused the activation of the abscission zone and fruit drop. By applying auxins externally, the level of fruit drop could be reduced. Yuan and Huang (1998), Zhang (1997), Stern and Gazit (1997) and Stern *et al.* (2001) have all reported reduced fruit drop in lychee by applying a range of auxins (e.g. NAA, 2,4-D and TPA). In other crops auxins and anti-ethylene compounds (e.g. AVG) have also been used to reduce fruit drop (Bangerth 1978; Raheme *et al.* 1997; Ebert and Bangerth 1985) and it would seem likely that this could also be the case in rambutan. The other plant growth regulator also involved in fruit abscission is abscisic acid (ABA). Abscisic acid is antagonistic to auxin synthesis so that factors that increase abscisic acid levels in the plant will decrease the auxin levels and lead to increased fruit abscission. Yuan and Huang (1998) measured ABA levels in lychee and found that high ABA levels were associated with increased fruit drop.

The mechanism of fruit drop in young fruit is different to the mechanism of abscission of leaves or mature fruit, which are triggered by the process of senescence. In this case, there is an increase in the levels of ethylene associated with the senescence process, which stimulates the hydrolytic enzymes in the abscission zone causing abscission.

## 2.1 Environmental and horticultural impacts on fruit drop

Environmental factors and horticultural practices are known to influence fruit drop in a range of crops. It is likely that these factors exert their influence by affecting the production and movement of plant growth regulators within the plant.

### 2.1.1 Environmental factors

#### Light

In many crops, fruit drop has been found to increase when trees are shaded, either naturally by overcast weather or by crowding from other trees or artificially by covering trees with shades. In apples Byers *et al.* (1991) and Byers and Wolf (1988) found that 2-4 days of continuous overcast weather could cause up to 98% of fruit to drop; however, if the overcast weather was interrupted by sunshine fruit drop was reduced. Similarly in citrus Goldschmidt (1999) and Ruiz *et al.* (2001) found low light conditions caused increased fruit drop. Quinlan and Preston (1971) also found shading increased fruit drop in apple, which they related to reduced photosynthetic levels. They measured photosynthetically active radiation and found it to be 80-90% lower in overcast, cloudy weather than in full sun. The association of low light levels, reduced photosynthesis and fruit drop has also been found in citrus.

Wien *et al.* (1989), working on cotton, found that shade treatments reduced photosynthesis and increased ethylene levels in cotton balls, which caused increased abscission. Treatments that increased photosynthesis reduced fruit drop. Similarly Byers *et al.* (1984) found reduced light conditions caused increased drop in peaches, which they believed to be related to reduced photosynthesis levels as well as changes in plant growth regulators.

In lychee, Yuan and Huang (1988) found fruit drop was enhanced by reduced solar radiation levels in overcast weather. These weather conditions (although fairly unlikely during lychee fruit development in Australia) are common during fruit development of rambutan, which often mature through the wet season. Yuan and Huang (1988) measured reduced photosynthetic levels and increased abscisic acid (ABA) levels in the fruit growing under shade. They concluded that the increase in the levels of ABA works in an antagonistic way to reduce the levels of auxins, thereby increasing fruit drop.

Mao *et al.* (1989) has suggested that shading works by changing the auxin transport systems within the plant rather than changes in photosynthesis or carbohydrate supply. The rapid response to shade treatments also suggests a hormonal response. Where growth was slowed (e.g. shading) auxin transport was reduced allowing ethylene to activate the abscission zone and fruit drop increased. By applying GA (a growth stimulant), auxin transport was increased and fruit drop reduced. The application of GA to rambutan fruit may work in a similar manner and should be investigated.

#### Water stress

Water stress generally increases fruit drop. Whiley and Schaffer (1997) found that ABA levels and ethylene biosynthesis increase under water stress in mango. The increase in ethylene then promotes hydrolytic enzyme activity in the abscission zone, which causes fruit abscission. In lychee excessive fruit drop has also been linked to water stress (Juan and Huang 1988). They found a link between ABA levels in the plant and fruit drop. Mitra and Dutton (2004) found increased ethylene levels in shoots of water stressed lychee trees while Guinn and Brummett (1987) and Cooper and Henry (1973) found increased abscisic acid levels and lower auxin levels in fruits on cotton bushes and citrus trees respectively under water stress. A similar response has been found with water logging in citrus (Goldschmidt 1999) and mammy sapote (Nickum *et al.* 2010), although in both cases the response was related to a decrease in photosynthesis. It is likely that long spells of overcast weather, low evaporation and soil water logging in rambutan orchards could also cause plant stress inducing a hormonal response similar to water stress resulting in fruit drop.

### Temperature

Temperatures, as well as affecting pollination and fertilisation of fruit, can affect fruit drop during fruit development. Byers and Smith (1998) found that high temperatures increased ethylene levels in apple trees and this led to an increase in fruit drop. Grausland (1978) also found high night temperatures increase ethylene production, which they related to increased fruit abscission. In citrus high temperatures increased the concentrations of growth retardants (e.g. ABA) and reduced the levels of growth promotants (e.g. GA) and this led to increased levels of fruit drop (Talon *et al.* 1997; Kojima *et al.* 1996).

It is concluded that any environmental factor that causes plant stress is likely to aggravate fruit abscission by increasing the levels of ethylene or the growth retardant ABA that stimulate ethylene synthesis, which in turn promotes the development of the abscission zone causing fruit drop.

## 2.1.2 Horticultural practices

### Girdling

Girdling is practiced in many fruit crops. It generally reduces vegetative growth and increases fruit retention. Trueman and Turnbull (1994) found girdling branches around flowering increased fruit numbers in macadamia while Zhon *et al.* (1996) also found girdling (spiral) conducted after flowering in lychee inhibited vegetative growth and reduced fruit drop. Increases in fruit retention associated with girdling have also been found in citrus, apple, avocado, olive and persimmon (Goren *et al.* 2004). The mechanism behind the increase in fruit retention again seems to be related to changes in the production and movement of plant growth regulators. Girdling blocks phloem transport that leads to a build up of photosynthates and growth regulators in the tree above the girdle. Several authors have measured increases in auxin concentrations in girdled branches and increased movement of auxins out of fruit, which is thought to prevent the abscission zone forming (Cutting and Bower 1990; Erner 1989; Goren *et al.* 2004).

### Growth regulators – auxins, abscisic acid and ethylene

Researchers working in various crops have been able to demonstrate that fruit abscission and fruit retention can be regulated by external applications of auxins, abscisic acid and ethylene or anti-ethylene compounds. These compounds are absorbed by the plants and alter the internal concentrations of these growth hormones that then influence the natural mechanisms of fruit abscission. Applying auxins (e.g. NAA, IAA, TPA or 2,4-D) increases the auxin levels in developing fruit, which in turn prevents ethylene from activating the abscission zone thus reducing fruit drop (Yuan and Huang 1998; Zhang 1997; Browning *et al.* 1992; Guinn and Brummett 1987; Talon *et al.* 1997; Gardner *et al.* 1940).

Application of aminoethoxyvinylglycine (AVG), an anti-ethylene compound, works in a similar way to the auxin applications. By inhibiting the synthesis of ethylene in the plant, the abscission zone cannot be activated and fruit drop is prevented. Fruit drop has been successfully reduced in apples (Greene 2002; Gardner *et al.* 1940; Byers 1997), pecan (Wood *et al.* 2009), citrus (Talon *et al.* 1997) and mango (Singh *et al.* 2005) with the use of AVG.

Working in the opposite manner, applications of ethylene or abscisic acid have been used to increase fruit drop in some crops. Applications of ethylene stimulate ethylene synthesis in the plant, which activates the abscission zone causing fruit drop. Application of abscisic acid suppresses auxin synthesis, which allows the ethylene in the plant to activate the abscission zone (Bangerth 2000).

It would seem likely that the application of either auxins (e.g. NAA, TPA) or anti-ethylene compounds (e.g. AVG) in the later stages of fruit development may be able to alter the hormonal balances involved in fruit abscission observed in rambutan following a period of overcast, wet weather and prevent fruit drop.

## Growth retardants

Growth retardants such as Alar, paclobutrazol, uniconizol or prohexadione-ca have been found to be effective at reducing fruit drop in mango (Singh *et al.* 2005), avocado (Wolstenholme *et al.* 1988), lychee (Mitra and Dutta 2004) and apple (Quinlan and Preston 1971). By restricting vegetative growth auxin production and transport from the vegetative shoots (which is a primary source of auxin production) is reduced, which allows the flow of auxin out of the fruit (a secondary source of auxin production) to proceed which prevents the abscission layer forming preventing fruit drop (Kohne and Kremor-Kohne 1987). Promoting vegetative growth when there are fruit developing is likely to have the opposite effect and increase fruit drop. Therefore, applying nitrogen-based fertilisers during the later stages of fruit growth would not be recommended. However, maintaining a reasonable level of nutrition is important because nutrient deficiencies can cause plant stress, which can lead to increased abscission (Singh *et al.* 2005).

# 3. Effect of 3,5,6-TPA on Fruit Drop

## 3.1 Introduction

The literature review indicates that fruit drop in most fruit trees is controlled by a balance of plant growth regulators, particularly auxin and ethylene. When auxin levels decline, the abscission zone becomes more sensitive to the growth regulator ethylene. The ethylene stimulates hydrolytic enzyme production (which causes cell walls to collapse) and the abscission layer forms causing fruit drop. In a number of crops (e.g. citrus, apples, lychee) applying auxins or anti-ethylene compounds to fruits when fruit abscission is likely to occur has been used to reduce fruit drop (Stern and Gazit 1997; Cooper and Henry 1973; Dal Cin *et al.* 2008).

In lychee, a closely related species to rambutan, research has shown that auxin levels within the developing fruit fall at the onset of embryo or seed development (Liu 1986). This stage of fruit development often coincides with periods of significant fruit drop. Researchers have found that applying synthetic auxins to the trees as foliar sprays can increase auxin levels within the plant and reduce fruit drop (Stern and Gazit 1997; Zhang 1997; Stern *et al.* 2001). The synthetic auxin 3,5,6-TPA has been used at 50ppm for this purpose.

Some yield loss is experienced every year in rambutan orchards from unwanted fruit drop. In some seasons, excessive fruit drop has caused major yield losses. Excessive fruit drop has mostly occurred in north Queensland when the late stages of fruit development has coincided with prolonged periods of very wet, overcast conditions. From experience in other crops (see literature review), it would appear that during these conditions there is a build up of ethylene and abscisic acid levels in the plant. These compounds inhibit auxin synthesis that, when levels decline sufficiently, allows ethylene to stimulate the abscission zone causing fruit drop.

Trials were established in north Queensland and the Northern Territory to determine if the synthetic auxin 3,5,6-TPA could be used to reduce fruit drop in rambutan orchards. The aim was to determine ideal rates and times of application.

## 3.2 Materials and methods

During 2008 and 2009, trials were conducted to examine the efficacy of the synthetic auxin 3,5,6 trichloro-2-phridyl-oxyacetic acid (3,5,6-TPA – registered name “TOPS”) on fruit drop. Trials were conducted on several commercial orchards in north Queensland and in the Northern Territory. Trials were conducted on a range of varieties, including R134, R167, Jitlee and Binjai.

Panicles with fruit varying in size from 10-25mm (4-9 weeks prior to harvest) in length were sprayed once with a 25ppm or 50ppm foliar spray plus wetter (0.01% Agral) of the synthetic auxin 3,5,6-TPA. Panicles were sprayed with 3,5,6-TPA using a hand sprayer until runoff. Spraying occurred late in the afternoon to reduce the chance of evaporative losses and improve the absorption of the 3,5,6-TPA. Fruit length was measured from the stem end to the tip from the base of the spinterns.

For each trial 60 panicles were marked (2-8/tree) over 10-20 trees. Half of the panicles were sprayed with auxin and the other half left as controls. For each panicle the number and size of fruit was recorded just prior to treatment (Figure 11). Fruit numbers were then recorded at harvest, 4-9 weeks later.

Data was analysed for statistical differences for each treatment using an analysis of variance. The efficacy was assessed by comparing the level of fruit drop on treated and untreated panicles.

**Figure 11. Panicle with excellent fruit set, tagged for fruit drop studies.**

## 3.3 Results and discussions

Fruit drop in rambutan trees was highly variable, ranging from less than 10% to more than 50% in control trees (Tables 7, 8 and 9). Fruit drop was generally highest when fruit was small (10-15mm in length) and declined as fruit developed toward maturity (20-25mm in length); however, this was not always the case. Observations of dropped fruit on control trees indicated that 20-40% of fruit 10-20mm in size appeared to be well formed and undamaged, while the remainder had damaged seed, split seed or the embryo was missing or had died. It is unlikely that any treatments would be able to rescue these damaged fruit; however, they may be able to prevent some of the healthy fruit from shedding.

**Table 7. Effect of 3,5,6-TPA (50ppm) application on fruit drop (from application to harvest) on panicles with fruit of various lengths. Trials conducted in north Queensland in 2008 on varieties R134, R167, R156, Jitlee and Binjai. Data is the average of 30 panicles.**

| Trial | Fruit length (mm) | Control | TPA |
|---|---|---|---|
| | | % fruit drop | |
| 1 | 15-20 | 50.7 | 39.7* |
| 2 | 20 | 36.4 | 34.0 |
| 3 | 20 | 21.6 | 17.0 |
| 4 | 20-25 | 52.6 | 24.2* |
| 5 | 25 | 8.9 | 3.9 |

* Significantly different (P=0.05).

**Table 8.** **Effect of 3,5,6-TPA (50ppm) application on fruit drop (from application to harvest) on panicles with fruit 10-15mm and 20-25mm in length. Trials conducted in the Northern Territory in 2008 on the varieties R134, R167 and Binjai. Data is the average of 30 panicles. Fruit drop significantly different (P=0.05).**

| Trial | Fruit length (mm) | Control | TPA |
|---|---|---|---|
| | | % fruit drop | |
| 1 | 10-15 | 45 | 23* |
| 2 | 25-30 | 25 | 11 |

* Only 14% of this fruit reached at marketable size at harvest compared to 81% in the control trees.

**Table 9.** **Effect of 3,5,6-TPA (25ppm and 50ppm) application on fruit drop (from application to harvest) on panicles with fruit of various lengths. Trials conducted in north Queensland in 2009 on varieties R134, R167, Jitlee and Binjai. Data is the average of 30 panicles. Figures followed by different letters are significantly different (P=0.05).**

| Trial | Fruit length (mm) | Control | 25ppm TPA | 50ppm TPA |
|---|---|---|---|---|
| | | % fruit drop | | |
| 1 | 20 | 29.5 ab | 33.0 a | 25.0 b |
| 2 | 20-25 | 19.4 c | 13.7 d | 5.7 e |
| 3 | 20-25 | 25.0 fg | 32.5 f | 21.9 g |

Applying 3,5,6-TPA to fruiting panicles generally reduced fruit drop, although sometimes not significantly (Tables 7, 8 and 9). The best reductions occurred when fruit drop was high in control trees, for example in Trials 1 and 4 in 2008 in north Queensland (Table 7) and Trial 1 in the Northern Territory (Table 8) where fruit drop in control trees was around 50%. In these cases applying 3,5,6-TPA greatly reduced fruit drop from around 50% to 25-40%, equivalent to a yield increase of 25-60%. When fruit drop in control trees was low (<10%), for example in Trial 5 in 2008 in north Queensland (Table 7), the effect of 3,5,6-TPA was reduced. Obviously, when there is only a small amount of fruit drop, the 3,5,6-TPA cannot have much of an effect on reducing it. At intermediate levels of fruit drop (20-30%) the response to 3,5,6-TPA was quite variable. In some cases fruit drop was greatly reduced, for example Trial 2 in the Northern Territory (Table 8) and Trial 2 in 2009 in north Queensland (Table 9). In other cases, for example Trials 2 and 3 in 2008 in north Queensland (Table 7), the 3,5,6-TPA application only reduced fruit drop marginally. The variable response may relate to the amount of fruit drop relative to the fruit size. When fruit drop is higher than might be considered normal for natural fruit drop, say above 40% for fruit 10-20mm in length or 20-25% for fruit 20-25mm in length, applying 3,5,6-TPA is effective at reducing the level of drop. When fruit drop in control trees is less than these levels applying 3,5,6-TPA is less effective.

Fruit size was also important in determining the response to 3,5,6-TPA, as has been found in lychee (Drinnan and Diczbalis 2009). In Trial 1 in 2008 in the Northern Territory (Table 8), although fruit drop declined from 45% to 23%, a lot of the fruit retained on the panicles did not develop properly and were too small to market. When 3,5,6-TPA is applied to small fruit (10-15mm in length), it seemed to hinder development and, although fruit drop was reduced, a lot of the fruit did not reach a marketable size. The trials indicate that 3,5,6-TPA should only be applied to fruit at least 20mm in length, or less than six weeks before harvest.

The trials conducted in north Queensland in 2009 (Table 9) indicated that applying 3,5,6-TPA at 50ppm reduced fruit drop to a greater extent than 25ppm. In the two years of trials no excessive fruit drop associated with very wet, overcast conditions (as can occasionally happen) occurred. It would seem likely from these results that 3,5,6-TPA application would help prevent this from occurring. This preliminary work indicates that further research on the use of 3,5,6-TPA is warranted. In future work it is suggested to trial higher rates of 3,5,6-TPA. Efficacy and residue data is still required to have 3,5,6-TPA registered for use in rambutan.

# Implications

The project has developed management strategies to overcome two major constraints on production in Australian rambutan orchards.  If adopted by the industry these strategies could significantly increase production, improving the commercial viability of the industry.  Improved economic viability would ensure continued growth of the industry, which would improve the economic outlook of the rural communities in which they are located via employment opportunities and increased demand for services. Improved and more consistent production will also help in market development for rambutan.

These two strategies (namely spot spraying foliar NAA on to developing flowers throughout the orchard and foliar spraying trees with 3,5,6-TPA when fruit are 20-25mm in length) are likely to be easily incorporated into normal management practices.  The cost of applying these treatments is estimated at less than $100/ha for the NAA and less than $500/ha for the 3,5,6-TPA.  The value of the yield increases recorded in these trials would far exceed (estimated at thousands of dollars) these additional costs.  The increase in early production by using NAA would also allow growers to capitalise on high, early prices.  It is anticipated that the NAA treatment may be even more effective at improving pollination when conducted across a whole orchard compared to doing individual trees (as done in these trials) because there would be more pollen spread more evenly throughout the orchard.

# Recommendations

The use of NAA to ensure the production of male flowers has the potential to markedly improve the productivity of rambutan trees, especially in years where seasonal and climatic conditions are conducive for early flowering. Given that the number of male flowers produced is always very low in rambutan, it is likely that using NAA during flowering at any time of the year is likely to be beneficial in improving pollination, fruit set and yield.

The results from this research suggest rambutan growers trial the use of NAA (once registered) on their varieties and in their growing conditions. An application for registration has been submitted to the APVMA. It is recommended growers spot spray evenly around trees and the orchard one in 15 or one per 2m² of flowering panicles just prior to flower opening with 40ppm NAA at 10-14 day intervals during the flowering period. This ensures plenty of male flowers will be present and, therefore, a good supply of pollen for pollination during the flowering period throughout the orchard. The NAA treatment worked on all varieties studied and at all locations in the Northern Territory and north Queensland. The only time NAA did not work was when the minimum temperatures following pollination were low (6-12°C). This may be an issue in some locations in some seasons. NAA treatments did not affect the pattern of maturity or fruit quality and no residues were detected. As a long term solution to improving pollination without having to rely on NAA sprays, researchers and growers have considered the merits of planting male flowering seedling trees or varieties that do produce some male flowers (e.g. the variety Silengkeng). However, these solutions do not guarantee male and female flowers will be open at the same time and in the same locations throughout the orchard, as occurs with NAA treatments. Also, male seedling trees produce very little or no crop; therefore, planting them instead of a variety will limit the yield potential.

The use of 3,5,6-TPA to reduce fruit drop in rambutan has the potential to improve production, although further research work on efficacy and residue analysis is required for registration. The preliminary trials conducted have shown some promising results. Applying 3,5,6-TPA at 50ppm as a foliar spray to trees with fruit 20-25mm in length can reduce fruit drop significantly. The reduction in fruit drop is greatest when fruit drop is high and least when fruit drop is low. It is recommended not to use 3,5,6-TPA on small fruit (<15mm) as some damage was observed. These promising results suggest further research on the use of 3,5,6-TPA is warranted. In future work it is suggested to trial higher rates of 3,5,6-TPA.

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# Boosting Rambutan Productivity through Improvements in Fruit Set

by James Drinnan and Mark Traynor

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The rambutan (*Nephelium lappaceum*) is a tropical, evergreen tree native to the humid, tropical regions of Malaysia and Indonesia where the climate is reasonably predictable and production fairly consistent. In Australian growing conditions production has been poor and inconsistent from season to season.

Two factors known to contribute towards this problem are poor fruit set due to poor pollination and excessive fruit drop during fruit development prior to maturity. The combination of these factors has severely impacted the productivity of trees and limited the expansion of the industry. Variable production from year to year has also created problems in market development.

The rambutan industry has highlighted these issues as key production constraints in their strategic plan.

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Cover photo: Rambutans produce predominantly female flowers, especially when they flower early in the season when temperatures are low.
Back cover photo: Poor pollination and fertilisation leads to the development of small (5-10mm), parthenocarpic fruit with no seed development.