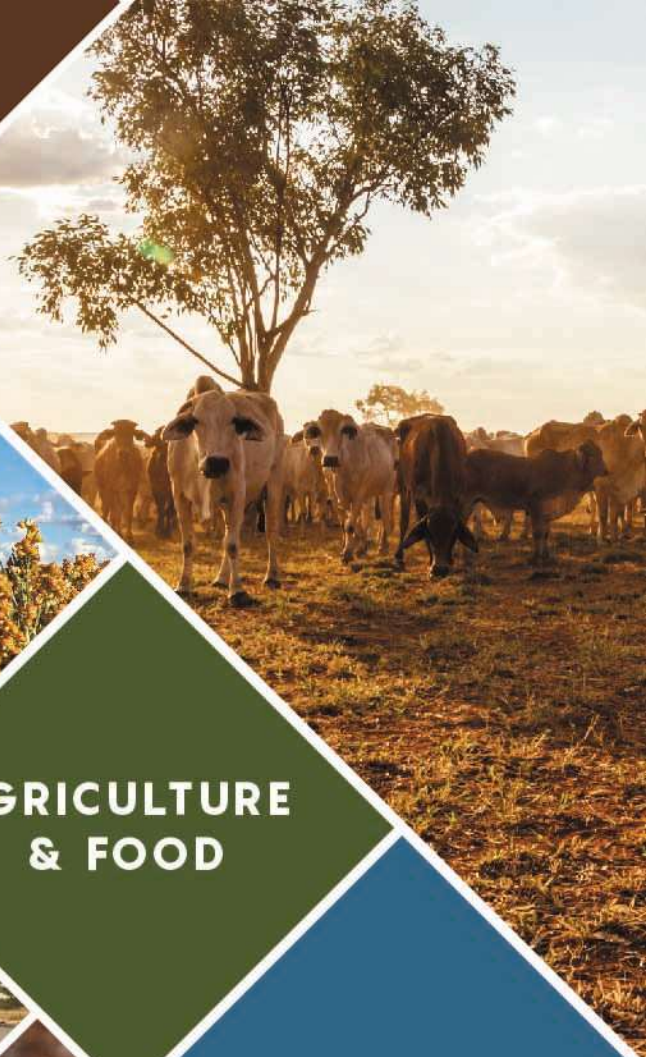
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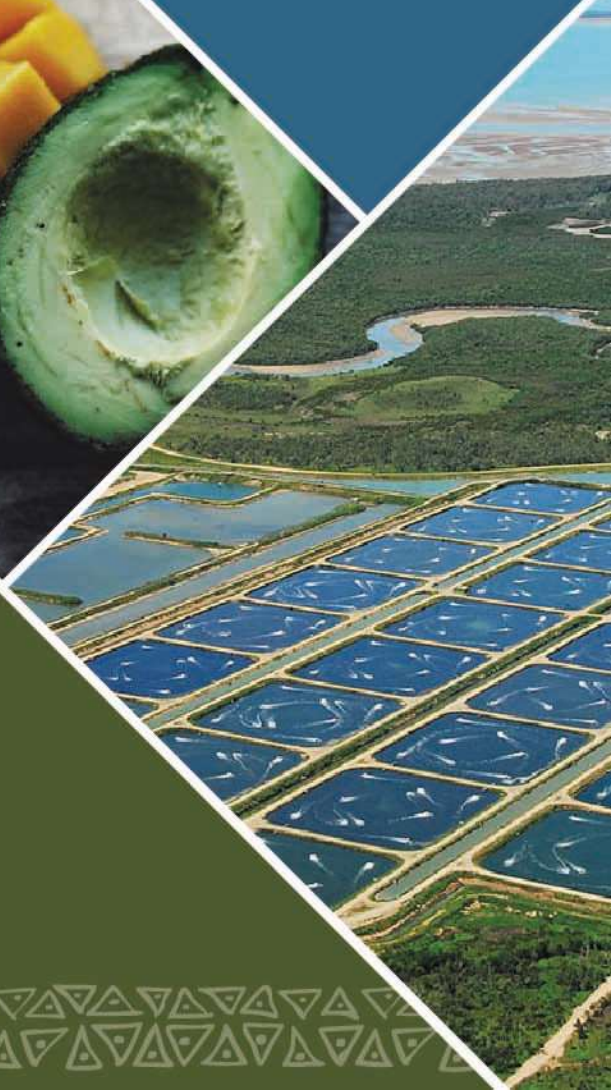




TRADITIONAL OWNER-LED DEVELOPMENT

AGRICULTURE & FOOD





Demonstrating Next-Generation Resilient Orchard Production Systems for Tropical Crops

Final Research Report – August 2024

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CRCNA

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Acronyms

ANOVA	Analysis of Variance
B	Boron
BFSP	Berrimah Farm Science Precinct
CPRF	Coastal Plains Research Farm
CRCNA	Cooperative Research Council for Northern Australia
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Cu	Copper
DAF	Department of Agriculture and Fisheries (Qld)
DITT	Department of Industry, Tourism and Trade (NT)
DPIRD	Department of Primary Industries and Regional Development (WA)
ECU	Edith Cowan University
Fe	Iron
GA	Gibberellic acid
HD	High Density
HDT	Ultra-high Density Trees
IAA	Indole-3- acetic acid
IBA	Indole-3- butyric acid
K	Potassium
LSD	Least Significant Difference
MAP	Mono-ammonium Phosphate
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
N	Nitrogen
NAA	Naphthyl acetic acid
NT	Northern Territory
NTDITT	Northern Territory Department of Innovation, Tourism and Trade
P	Phosphorous
S	Sulphur
SE	Standard Error
TC	Tissue Culture
TCSA	Trunk Cross-sectional Area
UHD	Ultra-high density
WA	Western Australia
Zn	Zinc

Project Participants

















Executive Summary

Jackfruit (*Artocarpus heterophyllus*) is emerging as a significant tropical fruit crop in Northern Australia, promising economic benefits due to its versatility and growing market demand. The region's tropical and subtropical climates, particularly in areas like the Wet Tropical Coast, the northern Atherton Tablelands in Queensland, Kununurra and Carnarvon in Western Australia, and Katherine in the Northern Territory, provide suitable conditions for jackfruit cultivation. However, the threat of cyclones and extreme temperatures pose a significant risk, impacting both production and infrastructure, highlighting the need for resilient orchard management practices.

To address these challenges, the Cooperative Research Centre for Developing Northern Australia (CRCNA) funded a multi-site research project from 2021 to 2024. Titled “Demonstrating Next-Generation Resilient Orchard Production Systems for Tropical Crops,” the project involved collaboration among the Department of Agriculture and Fisheries Queensland (DAF), the Northern Territory Department of Industry, Tourism and Trade (NTDITT), the Western Australia Department of Primary Industries and Regional Development (DPIRD), as well as NT Farmers, QFVG (Growcom), Manbulloo Ltd., and Aus-Ex Fruit. The primary objective was to investigate and demonstrate the effectiveness of various branch training techniques and trellising methods on jackfruit trees across diverse environmental conditions in Northern Australia, with a focus on enhancing cyclone resilience. The project’s timeline allowed for the assessment of young jackfruit trees prior to reaching full production. The research additionally focussed on evaluating different propagation materials, including cuttings, grafts, and seedlings. Trials were conducted at multiple sites in Queensland, Northern Territory, and Western Australia, assessing key growth parameters.

In Queensland, the trials revealed mixed results regarding trellising. The effectiveness of trellising varied based on branch training strategies and propagation types. Angled branch training consistently promoted vigorous growth across sites, whereas horizontal branch training also yielded positive results but with less consistency. Candelabra training performed poorly and is not recommended for promoting early growth. Propagation material showed that seedlings and grafted trees generally exhibited more vigorous early growth compared to cuttings, with grafted and cuttings trees also showing earlier flowering and fruiting. Throughout the project, extensive efforts were made to propagate jackfruit using cuttings, leading to the development of a successful cutting propagation protocol. By the project's end, this technique had been adopted by a nursery in Queensland to produce clonal material for the growing jackfruit industry. Further research is needed to understand the long-term effects of tree training and propagation materials on fruiting patterns. Additionally, ultra-high-density planting slowed early growth compared to high-density plantings, though minor spacing variations had limited impact.

In Western Australia, the project highlighted the need for adaptable orchard management practices due to extreme weather conditions. Trellis systems provided mixed results, with potential future benefits for mechanisation and protection against cyclones. Initial findings suggest that the cost and labour implications of trellising might outweigh the benefits at this stage. The identification of suitable propagation material was a success, with certain varieties (C2, CP47, GUG, MOR) showing promise under WA conditions. Future research should focus on the genetics, clonal propagation, and agronomy of these varieties. Effective management of irrigation, temperature, light, and disease proved crucial, with precision irrigation and companion cropping offering potential solutions to enhance resilience and productivity.

In the Northern Territory, the project made significant strides in jackfruit propagation techniques. Traditionally, the Australian jackfruit industry has relied on non-clonal seedling plants, which resulted in inconsistent fruit quality and timing of harvest. The project established trials to evaluate various propagation methods, including grafting, marcotting, cuttings, and Tissue Culture (TC). While vegetative methods faced challenges such as disease control and low propagule numbers, TC emerged as the most promising technique, enabling the production of 15+ disease-free plants from a single 1 cm plant tip. At the conclusion of the project, the TC plants had not yet been tested under field conditions. Acclimatisation and field testing will be included in the ongoing monitoring process to validate the effectiveness of the propagation methodology in producing clean and substantial numbers of propagules for planting material. A field trial investigated different orchard designs and monitored clonal materials. Though these plants have not yet reached maturity, they will continue to be monitored for fruit set and yield until 2025/26. The project also involved industry extension, additionally, a doctoral research project, supported by NTDITT, is underway, with a PhD student anticipated to submit their thesis by the end of 2024.

Overall, the project offers valuable insights into optimising jackfruit orchard management practices, emphasising the importance of selecting appropriate branch training systems, propagation methods, and planting densities. The findings also underscore the critical need for resilient orchard designs to mitigate the risks posed by cyclones. Further long-term studies are required to fully understand the impacts on tree vigour and fruit production, contributing to the development of a resilient and profitable jackfruit industry in Northern Australia.

Introduction

Jackfruit (*Artocarpus heterophyllus*) is emerging as a significant tropical fruit crop in Northern Australia, offering potential economic benefits due to its versatility and growing demand in both domestic and international markets. Despite its potential, the commercial production of jackfruit faces several challenges, particularly in relation to tree management practices that optimise growth, yield, and fruit quality. Traditional methods often fail to address the specific needs of this crop under varying climatic conditions, leading to inconsistent production outcomes.

Recognising these challenges, the Cooperative Research Centre for Developing Northern Australia (CRCNA) funded a multi-site research project from 2021 to 2024. The project, titled “Demonstrating Next-Generation Resilient Orchard Production Systems for Tropical Crops”, was a collaborative effort involving the Department of Agriculture and Fisheries Queensland (DAF), the Northern Territory Department of Industry, Tourism and Trade (NTDITT), the Western Australia Department of Primary Industries and Regional Development (DPIRD), and several industry partners. The primary objective was to investigate and demonstrate the efficacy of various branch training techniques and trellising on jackfruit trees across different environmental conditions in Northern Australia. The work also involved evaluation of high-density tree establishment. The project’s timeline focused on the development of juvenile trees, and further work is required for assessing the effectiveness of different training systems on the growth and productivity of mature jackfruit trees.

In addition to evaluating branch training methods, the project also explored the performance of different propagation types, including cuttings, grafts, and seedlings. Currently jackfruit is propagated by grafting trees with a low and inconsistent success rate. In this project, diverse types of clonal propagations were explored to overcome the issue of scarcity of planting material that is one of the fundamental constrains for a good thriving horticultural industry. This comprehensive approach allowed the researchers to assess not only the impact of training techniques on tree growth and productivity but also the suitability or otherwise of trees propagated using different methods to higher density planting systems.

This project was conducted at eight trial sites across Queensland, the Northern Territory and Western Australia, encompassing a range of climatic zones from tropical to semi-arid environments. Four of these sites were established on commercial farm properties and were co-designed and managed in partnership with the farmer. This strategy known as ‘Farmer Participatory Research’ (also ‘Participatory Action Research’) emphasises collective enquiry and experimentation guided by farmer experience, practicality and commerciality to achieve improved research outcomes and greater practice adoption. This method has proven highly successful in facilitating positive practice change within the mango industry across northern Australia (Dickinson et al., 2023). The research conducted at these trial sites focused on evaluating key growth parameters, including tree height, trunk diameter or cross-section, and flowering and fruit status. The goal was to identify the most effective techniques for improving jackfruit production in terms of both quantity and quality.

The findings from this project are intended to provide practical, science-based recommendations for jackfruit growers, contributing to the development of a resilient and profitable jackfruit industry in Northern Australia. This report presents the results from each trial site, offering insights into how different branch training methods perform under varying environmental conditions and outlining best practice guidelines for the industry.

Chapter 1: Queensland trial sites

Introduction

This project involved eight demonstration trials across northern Australia, with four key sites located in Queensland: the South Johnstone Centre for Wet Tropics Agriculture, Bellenden Ker near Babinda, Mutchilba near Mareeba, and Laudham Park near Townsville (figure 1). These sites can be classified into wet tropics (South Johnstone and Bellenden Ker) and dry tropics (Mutchilba and Laudham Park), each exhibiting unique climatic conditions that may impact their suitability for jackfruit production.

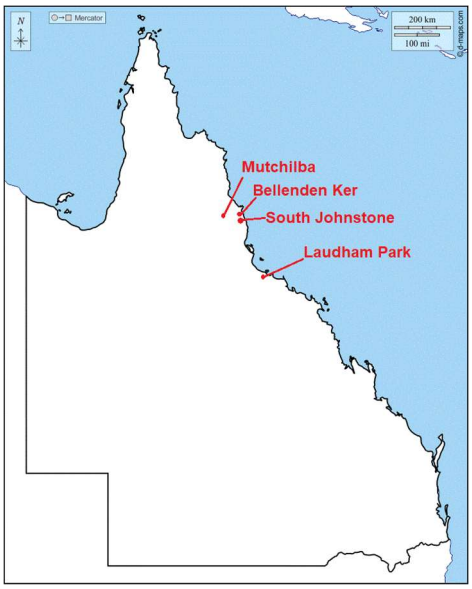


Figure 1. A map of Queensland showing the locations of the four trial sites.

Various trellising, tree training, types of planting material, and planting density approaches were assessed across the Queensland locations to evaluate their effectiveness in establishing resilient orchard systems for tropical crops, using jackfruit as the model. Given the limited data collection period regarding tree age, most of the collected data will be useful for informing early tree vegetative development over the first 12 to 24 months after planting.

During the trials, soil moisture was monitored, and onsite weather conditions were recorded for the South Johnstone site. Due to the juvenility of the trees at the time of reporting, it is not possible to draw conclusions regarding the impact of soil moisture distribution or climate on tree growth. However, the soil moisture data for all four sites, and weather data for South Johnstone, are included for comprehensiveness.

Tree growth measurements included tree height and trunk diameter. For the purpose of this report, the trunk diameter data was used to estimate trunk cross-sectional area development. For fruit trees, trunk cross-sectional area is an important method for defining vegetative vigour (Khatamian and Hilton, 1977; Nesme et al., 2005; Jupa et al., 2021). Therefore, it may be a useful quantification for assessing the early growth of jackfruit trees in this project.

Although reproductive development is expected to be limited for juvenile jackfruit trees, we report the proportion of trees with flowers or fruit present by the last few tree growth measurement dates for some of the sites, as described later.

Therefore, the main objectives of this chapter are to report, for the Queensland sites, on 1) soil moisture distribution for each site without drawing conclusions about its effect on tree development, 2) tree height development, 3) trunk cross-sectional area development, 4) apparent changes in the rate of trunk cross-sectional area development, and 5) the emergence of flowers and fruit.

Site 1: South Johnstone

Site Description

The jackfruit demonstration trial at South Johnstone is located at the Queensland Department of Agriculture and Fisheries' Centre for Wet Tropics Agriculture. The soil type is Innisfail Series, with a volcanic alluvial clay loam texture (Heiner and Smith, 1990). The trees of the 'Rajang' cultivar were planted on 16 November 2022 and include both a high density spaced trial and an ultra-high density planting trial. The site consisted of six rows in total, with four rows being jackfruit trees (figures 2 & 3). The distance between rows was 5 meters. The end-trees on each side of the rows were designated guard trees to avoid edge effects, while data was collected from the remaining trees within the rows. A total of nine trees were monitored for each row. All trees were grown on trellises with timber posts, with either six or four posts per 33-meter long row. High tensile fencing wires were installed at heights of 40, 110, 180, and 250 cm above ground level.



Figure 2. Jackfruit demonstration trial.

For the high-density trial, cuttings were used as the planting material. Three distinct training systems were evaluated: 1) horizontal cordon, angled branches, and candelabra (figure 4). Each training system consisted of three-tree plots, replicated three times (n = 9), in a randomised block layout design. The distance between trees was 3 meters, resulting in 667 trees per hectare being established.

For the ultra-high-density trial, a single row comprising 17 trees in total, propagated from both seedlings and cuttings, was established and monitored (figure 5). Three tree spacings were evaluated: 1 m, 1.5 m, and 1.8 m, resulting in 2,000, 1,333, and 1,111 trees per hectare, respectively. For the 1 m spacing, four cuttings (n = 4) and four seedling trees (n = 4) were established. For the 1.5 m spacing, three cuttings (n = 3) and two seedling trees (n = 2) were established. For the 1.8 m spacing, two trees of each planting material type were used (n = 2). All ultra-high-density trees had the central leader secured to the trellis wire, but branches remained untrained. For the results presented in this report, we considered the 1 m spacing for both cuttings and seedlings, as well as the 1.5 m spacing for cuttings, based on the number of replicates.

In February 2023, two additional trellised rows were planted with different tropical fruit species. Row five was planted with grafted rambutan ('Binjai' cultivar) at 2.8 m spacing, and Row six with durian seedlings at 2.2 m spacing. Since these trees were still very young at the time of reporting, no further data regarding the rambutan and durian trees will be reported; however, they will be useful for future field demonstrations.

Guard	Guard	Guard	Guard	Durian	Rambutan
UHD	Trel-A	Trel-Can	Trel-H	Durian	Rambutan
UHD	Trel-A	Trel-Can	Trel-H	Durian	Rambutan
UHD	Trel-A	Trel-Can	Trel-H	Durian	Rambutan
UHD	Trel-H	Trel-A	Trel-Can	Durian	Rambutan
UHD	Trel-H	Trel-A	Trel-Can	Durian	Rambutan
UHD	Trel-H	Trel-A	Trel-Can	Durian	Rambutan
UHD	Trel-Can	Trel-H	Trel-A	Durian	Rambutan
UHD	Trel-Can	Trel-H	Trel-A	Durian	Rambutan
UHD	Trel-Can	Trel-H	Trel-A	Durian	Rambutan
Guard	Guard	Guard	Guard	Durian	Rambutan
R1	R2	R3	R4	R5	R6

Figure 3. Trial layout at South Johnstone. Row one (R1) consists of ultra-high density planting trellised jackfruit trees (UHD), whereas rows two to four consist of high density (HD) trellised jackfruit trees. Rows five and six were additionally established with rambutan and durian trees, respectively. Trel-A: trellised with angled branched; Trel-H: trellised with horizontal branches; Trel-Can: trellised with candelabra training.



Figure 4. Candelabra tree branch training system.



Figure 5. Ultra-high density demonstration trial. Example of 1m spacing between trees.

Tree training and agronomical inputs

Shortly after planting, trees were tied to the first trellis wire to protect them from wind or other damage. Once trees grew higher than the top trellis wire (250 cm), they were trimmed back to the height of the top wire.

As a rule of thumb, the young trees were irrigated three times a week, in the absence of rain, to prevent water stress and promote root development and vegetative growth. After six months from planting, irrigation was scheduled for two to three times a week for about three hours per event, depending on weather conditions.

Fertiliser was broadcast every six weeks using Nitrophoska, a nitrogen, phosphorus, and potassium-based compound fertilizer. The application started at 50 g per plant at the time of planting and gradually increased to 200 g per plant by the third year after planting.

General pest and disease management inputs were applied according to standard farm protocols.

Branches for each training system were tied to the wire with rubber ties. In the horizontal branch training system, juvenile branches were bent and tied to the wire. The process was performed monthly, especially during periods of intensive vegetative growth in spring and summer. Branches between wires were removed to facilitate the growth of the horizontal branches.

In the angular branch training system, a similar process was followed. Juvenile branches were tied to the wire at 45° angles, and other branches were removed. In both systems, the central leader remained the main component of the tree's scaffolding architecture.

In the candelabra training system, two opposite juvenile branches were trained horizontally on the bottom wire, and the secondary branches were removed to promote horizontal growth. From these two horizontally branches, at a distance of 50 to 70 cm from the main trunk, one vertical branch was allowed to grow on each side of the main leader, forming a total of three leaders in the tree’s scaffolding architecture.

Measurements and data collection

Soil moisture percentage was monitored using capacitance probes installed at depths of 20, 40, 60, 80, 100, and 120 cm. Measurements were taken at 30-minute intervals. For simplicity, the mean monthly soil moisture percentages from March 2023 and January 2024 were determined for depths of 20 cm (shallow), 80 cm (mid-profile), and 120 cm (deep) (figure 10).

Climatic conditions (rainfall, minimum and maximum temperatures and solar exposure) were obtained from an on-site weather station from when the trees were planted until January 2024 (figures 7, 8 and 9). The weather data were obtained from the Bureau of Meteorology website.

Tree heights and trunk diameters were measured on 26 May, 27 July, and 9 November 2023, approximately 6, 8, and 12 months after the trees were planted. Tree height was measured from the base of the trunk at ground level to the apex of the canopy. Trunk diameter was measured at 20 cm above ground level. The trunk cross-sectional area (TCSA) was subsequently estimated using the following formula: TCSA = $\pi(radius)^2$. The rate of TCSA expansion was determined by considering the days between each measurement. Since trees were topped once they reached the top trellis wire, trunk cross sectional area may be a better reflection of overall tree vigour in the case of this trial.

Given the juvenility of the trees at this site, no data on tree flowering or fruiting status will be reported here.

Data analysis

Where applicable, the analysis of variance (ANOVA) was used to test the significance of differences for each variable. Fisher's least significant difference (LSD) test was used to identify significant differences between means at $P < 0.05$. Significant differences between variables are indicated with different letters in the figures. Where no letters appear in the figure, no significant differences were found between variables at the specific timepoint.

Results

Weather conditions and soil moisture

The seasonal wet tropics rainfall pattern is illustrated in figure 6, where rainfall was particularly high during the summer months. Notably, from December 2022 to April 2023, rainfall was especially heavy. Another period of extremely high rainfall occurred in December 2023 and January 2024, with rainfall exceeding 600 mm in December, coinciding with the impact of Cyclone Jasper, which affected the region in December 2023. Mean monthly rainfall was lower in November 2022 and in October and November 2023, with less than 75 mm recorded per month. Intermediate rainfall, ranging between 75 and 250 mm per month, was recorded from May to September 2023.

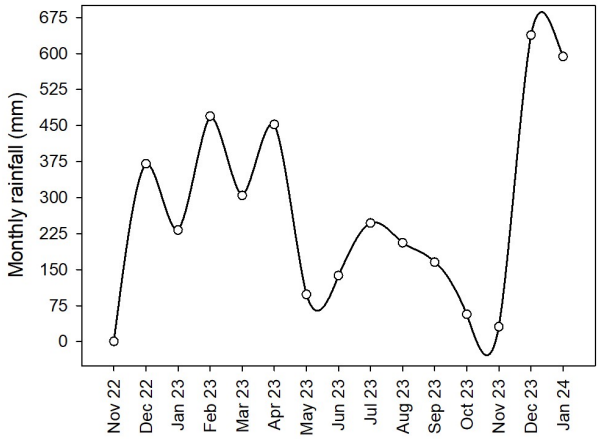


Figure 6. Mean monthly rainfall at South Johnstone from November 2022 to January 2024.

During the recorded period, the mean monthly maximum temperature ranged from 24.3°C in July 2023 to 32.2°C in January 2024 (figure 7). The mean monthly minimum temperature ranged from 16.3°C in August 2023 to 24.3°C in January 2024. The difference between the mean monthly maximum and minimum temperatures was minimal (8°C), which is typical of tropical climates.

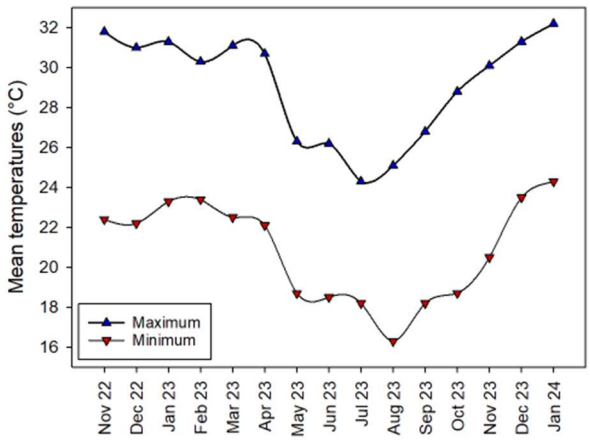


Figure 7. Mean monthly maximum and minimum temperatures at South Johnstone from November 2022 to January 2024.

Solar exposure was lower during the winter months and highest in spring 2023, particularly between October and November (figure 8). Solar exposure notably dropped in December 2023, coinciding with the impact of Cyclone Jasper.

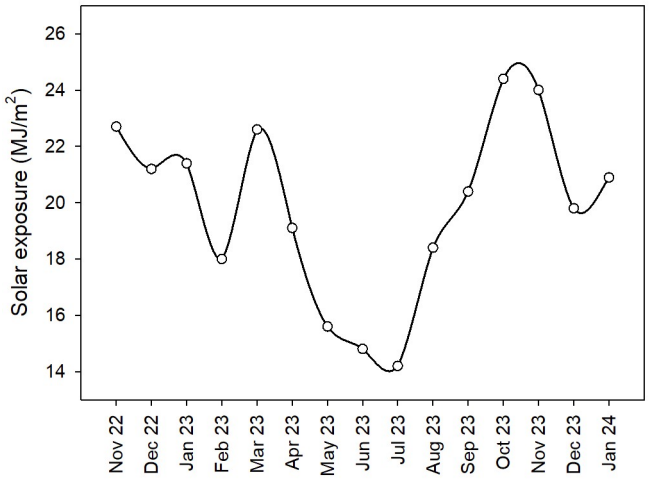


Figure 8. Mean monthly solar exposure at South Johnstone from November 2022 to January 2024.

Variation in soil depth had a relatively minor effect on water content distribution, with moisture percentage remaining between 32 and 38% across the depths from March to October 2023 (figure 9). The effects of the drop in rainfall around October 2023 can be seen in the steep decline in soil moisture in November 2023, especially in the shallow and mid-soil profiles. During the same period, the deep soil retained moisture quite well. There was a noticeable replenishment in soil moisture following the elevated rainfall from December 2023.

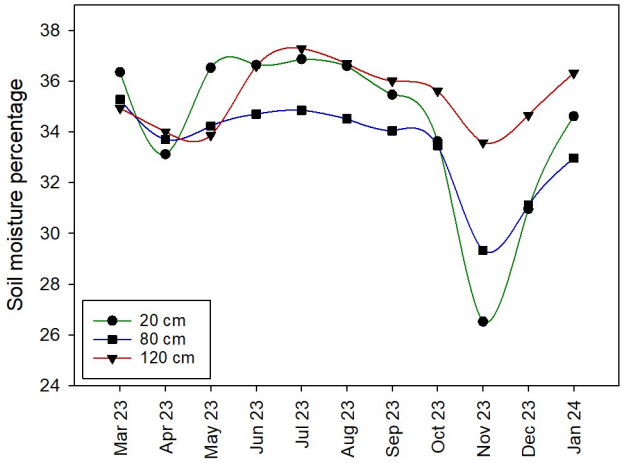


Figure 9. Mean monthly soil moisture percentage at South Johnstone from March 2023 to January 2024 at depths of 20, 80 and 120 cm.

Tree growth

Since the South Johnstone site contained trees with various training systems, propagation types, and planting densities, planted at different times, the tree growth measurement results (height, trunk cross-sectional area, and trunk cross-sectional area expansion rate) in the figures below compare:

1. Three training systems for trees propagated as cuttings (figures 10, 14, and 18).
2. Propagation types (cuttings or seedlings) for trees planted at 1 m tree spacing (ultra-high density) (figures 11, 15, and 19).
3. Trees planted at 1 m or 1.5 m ultra-high-density tree spacing (figures 12, 16, and 20).
4. Additionally, to compare growth characteristics between high density spaced trees and those at ultra-high density, heights and trunk cross-sectional area comparisons of all trees propagated as cuttings were conducted for the final measurement date (figures 13 and 17).

Tree height and development

In the high-density trellised training system trial, at six months after planting, the heights of trees in the three different training systems were not significantly different (figure 10). However, in the subsequent months, trees trained in the angled and horizontal systems exhibited rapid elongation, whereas those in the candelabra training system remained relatively consistent. By the final measurement in November 2023, the candelabra-trained trees still exhibited reduced heights compared to the other two systems.

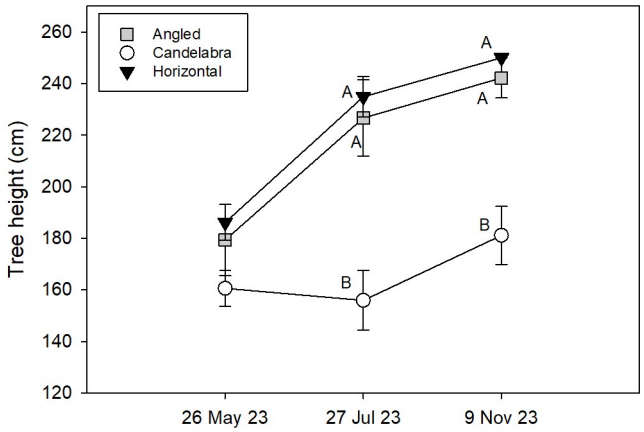


Figure 10. Tree height development during the first year after planting of jackfruit trees propagated from cuttings and trained with either angled, candelabra, or horizontal branch training. The different letters represent significant differences among tree training treatments ($P < 0.05$; mean ± SE).

Within the ultra-high-density trial, among the trees planted at 1-meter spacing, those propagated as seedlings consistently exhibited greater heights compared to those propagated as cuttings at each measurement date (figure 11). For the seedlings, the effect of tree topping above the top wire at 250 cm is visible after 27 July 2023.

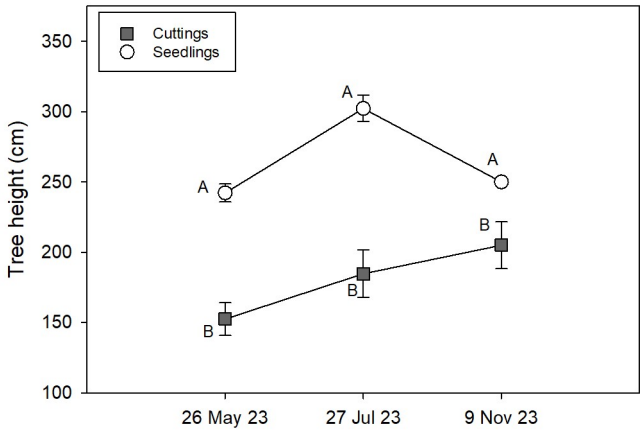


Figure 11. Tree height development during the first year after planting of jackfruit trees propagated from either cuttings or seedlings and planted at 1 m high-density spacing between trees. The different letters represent significant differences among tree training treatments ($P < 0.05$; mean ± SE).

No differences were observed in terms of tree height development during the first year after planting when comparing trees propagated from cuttings and spaced at either 1 or 1.5 meters between trees in the ultra-high-density trial (figure 12).

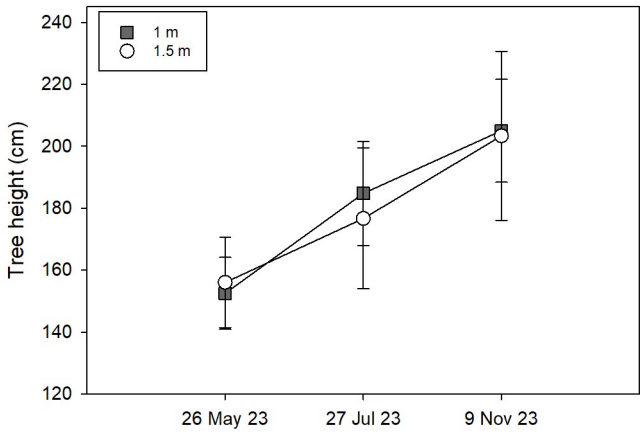


Figure 12. Tree height development during the first year after planting of jackfruit trees propagated from cuttings and planted at 1 or 1.5 m ultra-high density spacing between trees (mean ± SE).

At the final measurement date, one year after planting, a comparison between trees propagated from cuttings in the high density trellis trial (angled, candelabra, and horizontal training) and the ultra-high density trial (1 and 1.5 m plant spacing) showed that the angled and horizontally trained trees exhibited greater heights than those in the candelabra training and both ultra-high density planting spacings (figure 13).

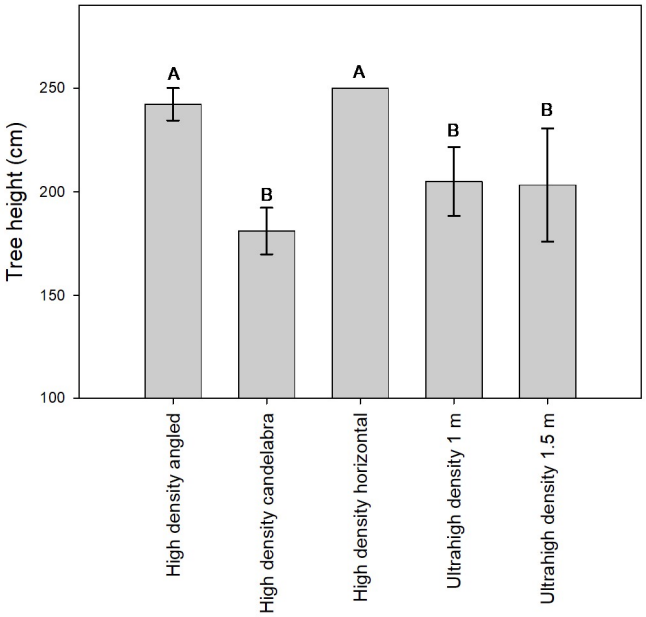


Figure 13. Tree height at one year after planting of jackfruit trees propagated from cuttings and planted at either high density (3 m) spacing with the different branch training systems or at ultra-high density of 1 or 1.5 m spacing between trees. The different letters represent significant differences among treatments ($P < 0.05$; mean ± SE).

Trunk cross-sectional area

The first significant difference in trunk circumference and cross-sectional area between the training systems was noted by November 2023, one year after planting (figure 14). The candelabra-trained trees exhibited a reduced trunk cross-sectional area compared to the angled and horizontal training systems.

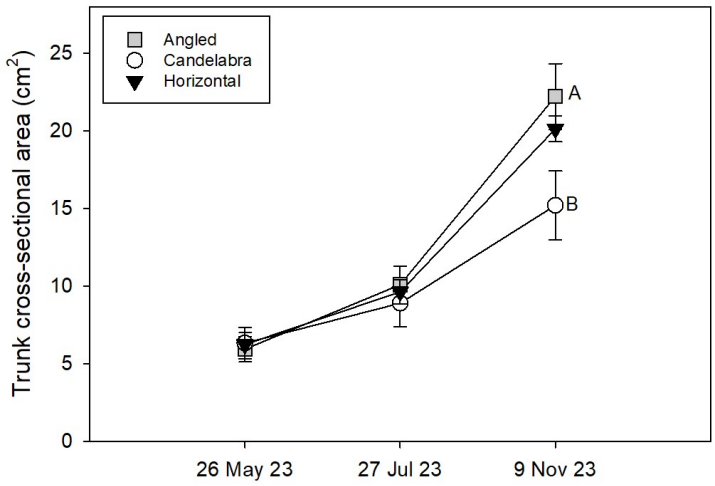


Figure 14. Trunk cross-sectional area development during the first year after planting of jackfruit trees propagated from cuttings and trained with either angled, candelabra, or horizontal branch training. The different letters represent significant differences among tree training treatments (P < 0.05; mean ± SE).

For trees planted at ultra-high density, those propagated from seedlings exhibit greater trunk cross-sectional areas compared to trees propagated from cuttings (figure 15). This trend was observed at each measurement date.

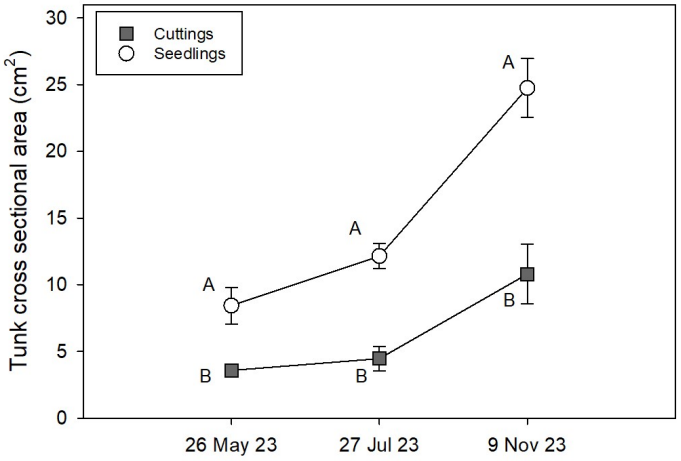


Figure 15. Trunk cross-sectional area development during the first year after planting of jackfruit trees propagated from either cuttings or seedlings and planted at 1 m ultra-high density spacing between trees. The different letters represent significant differences among tree training treatments (P < 0.05; mean ± SE).

Over the first 12 months after planting, no difference in trunk cross-sectional area development was observed between trees planted at 1 m or 1.5 m spacing (figure 16). There was no noteworthy increase in trunk cross-sectional area during the initial months, but a significant increase was observed over the final three to four months.

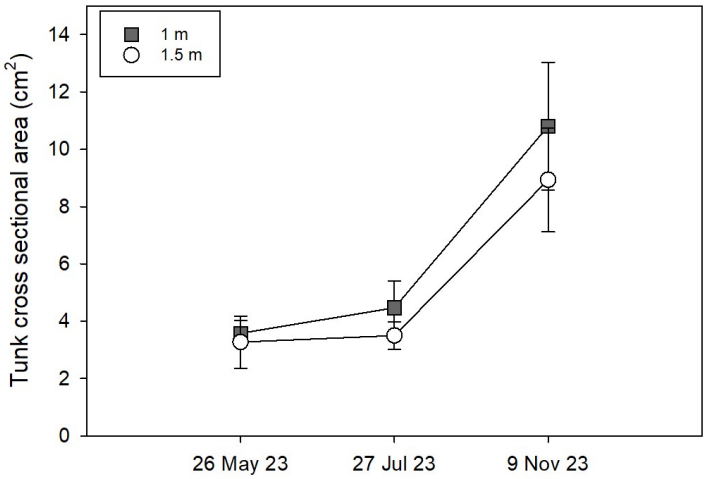


Figure 16. Trunk cross-sectional area development during the first year after planting of jackfruit trees propagated from cuttings and planted at 1 or 1.5 m ultra-high density spacing between trees (mean ± SE).

At the final measurement date, the trunk cross-sectional area was significantly reduced for the two ultra-high density planting systems compared to the high density angled and horizontal trained trees (figure 17). Additionally, the angled-trained trees exhibited greater trunk cross-sectional areas than the horizontal-trained trees.

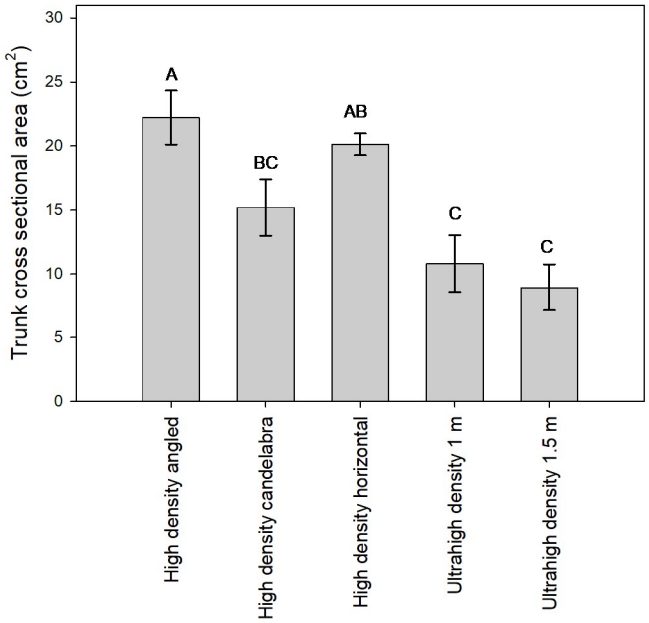


Figure 17. Trunk-cross sectional area at one year after planting of jackfruit trees propagated from cuttings and planted at either high density (3 m) spacing or at ultra-high density of 1 or 1.5 m spacing between trees. The different letters represent significant differences among treatments ($P < 0.05$; mean ± SE).

Trunk cross sectional-area expansion rate

A significant difference was observed between May 26 and July 27, 2023, where the candelabra-trained trees showed slower trunk expansion compared to the angled-trained trees (Figure 18). Between July 27 and November 9, 2023, the candelabra-trained trees also exhibited a slower rate of trunk expansion compared to both the angled and horizontally trained trees. An increase in the rate of trunk expansion was noted in the second interval relative to the first for both the angled and horizontally trained branches.

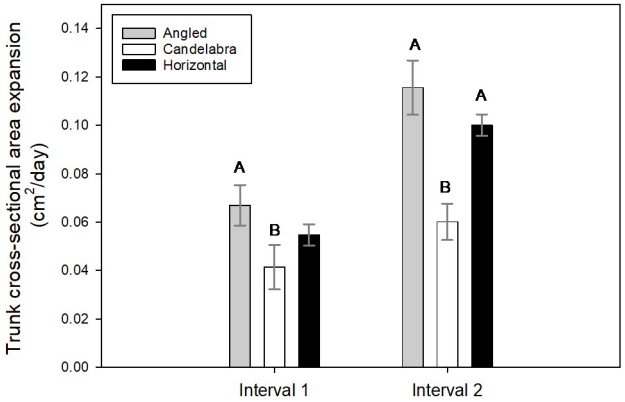


Figure 18. Trunk cross-sectional area expansion rate during the first year after planting of jackfruit trees propagated from cuttings and trained with either angled, candelabra, or horizontal branch training. Intervals 1 and 2 refer to the periods between subsequent measurement dates, thus 26 May to 27 July 2023, and 27 July to 9 November 2023, respectively. The different letters represent significant differences among tree training treatments ($P < 0.05$; mean ± SE).

Under an ultra-high planting density, the seedling trees showed greater trunk expansion rates than the cuttings in both intervals between the measurement dates (figure 19). However, the growth rates increased for both types of trees between July 27 and November 9, 2023.

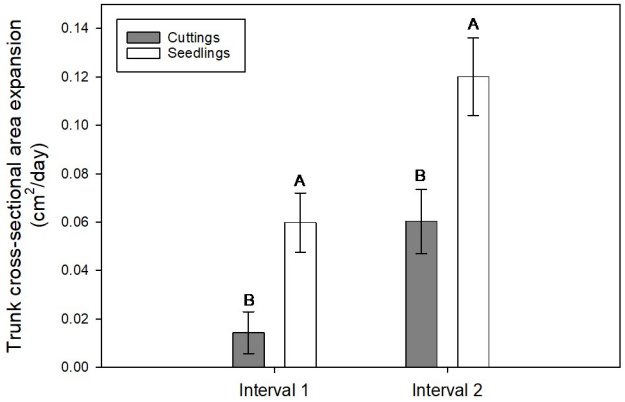


Figure 19. Trunk cross-sectional area expansion rate during the first year after planting of jackfruit trees propagated from either cuttings or seedlings and planted at 1 m ultra-high density spacing between trees. Intervals 1 and 2 refer to the periods between subsequent measurement dates, thus 26 May to 27 July 2023, and 27 July to 9 November 2023, respectively. The different letters represent significant differences among tree training treatments ($P < 0.05$; mean ± SE).

The trunk cross-sectional area expansion rate did not differ between trees planted at 1 or 1.5 m spacing in both intervals (figure 20). However, there was a notable increase in the expansion rate for both densities during the second interval.

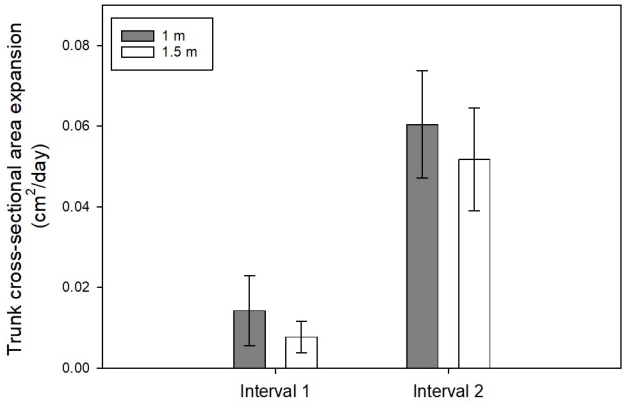


Figure 20. Trunk cross-sectional area expansion rate during the first year after planting of jackfruit trees propagated from cuttings and planted at 1 or 1.5 m ultra-high density spacing between trees. Intervals 1 and 2 refer to the periods between subsequent measurement dates, thus 26 May to 27 July 2023 (8 weeks), and 27 July to 9 November 2023 (15 weeks), respectively (mean ± SE).

Discussion and conclusions

Results from the South Johnstone trials have revealed various implications regarding the choice of branch training strategy, propagation material, and planting density on the growth of young jackfruit trees within the first year after planting.

Trends in seasonal weather conditions did not noticeably affect tree growth. However, this is likely due to the limited number of measurements for tree height and trunk diameter, which restricts the ability to assess growth rates at different times of the year or in relation to climate and soil moisture.

Branch training strategies significantly impacted the elongation and trunk growth of trellised jackfruit trees within the first year after planting. Specifically, candelabra training appears to negatively affect early tree vegetative development compared to angled or horizontally trained branches. Therefore, for accelerated growth, growers should consider employing angled or horizontal branch training systems. The candelabra training system, while limiting early growth, may be suitable where slower initial growth is desired.

Jackfruit trees propagated from seedlings exhibit an apparent advantage over those from cuttings in terms of early growth. This trend is evident within ultra-high density planting systems, where seedlings show more robust growth compared to cuttings.

Ultra-high planting density tends to slow early tree growth compared to high density plantings with trellised trees. However, this effect is influenced by the type of branch training applied. Within the ultra-high-density systems, minor differences in planting density appear to have no significant effect on early tree growth.

Site 2: Bellenden Ker

Site description

The Bellenden Ker site is located on a commercial property operated by Aus-Ex Fruit. The soil consists of the Pin Gin and Bingil series, characterized by well-drained sandy loam (Heiner and Smith, 1990). Grafted 'Rajang' jackfruit trees and those propagated from cuttings were planted on 15 November 2021 and 20 April 2022, respectively. These trees were trellised using different branch training techniques or left free-standing, as described below, and spaced at high density between trees. An additional trial of seedlings planted at ultra-high density was established on 19 February 2022.

The layout features seven datum rows surrounded by guard trees (figure 21). The ultra-high-density plantings were situated in the central row, while the grafted trees and those from cuttings were arranged in a randomized block design across the other six rows. The distance between rows is 6 meters.

In the high density spaced rows, the distance between trees is 3 meters. Three tree training strategies were evaluated: free-standing trees and trellised trees with either central leader with angled branch training (figure 23) or central leader with horizontal branch training (figure 24). For each training method, 16 trees were planted for each propagation type (n = 16). The trees of each training and propagation type were planted in plots of four, replicated four times throughout the block.

Grafts	48		SWS = Single Wire Support						
Cuttings	48		Trel-A = Trellis Angle Branches			F	F	F	F
Filler	70		Trel-H = Horizontal Branching			F	F	F	F
Guard	50		Free = Free standing			F	F	F	F
HDT	48	F	F	F	F	F	F	F	F
F	F	F	F	F	F	F	F	F	F
F	F	F	F	F	F	F	F	F	F
G - SWS	G	G	G	G	G	G	G	G - SWS	F
G - SWS	Trel-A	Free	Trel-H	HDT	Free	Trel-H	Trel-A	G - SWS	F
G - SWS	Trel-A	Free	Trel-H	HDT	Free	Trel-H	Trel-A	G - SWS	F
G - SWS	Trel-A	Free	Trel-H	HDT	Free	Trel-H	Trel-A	G - SWS	F
G - SWS	Trel-A	Free	Trel-H	HDT	Free	Trel-H	Trel-A	G - SWS	F
G - SWS	Trel-A	Free	Trel-H	HDT	Free	Trel-H	Trel-A	G - SWS	F
G - SWS	Trel-A	Free	Trel-H	HDT	Free	Trel-H	Trel-A	G - SWS	F
G - SWS	Trel-A	Free	Trel-H	HDT	Free	Trel-H	Trel-A	G - SWS	F
G - SWS	Trel-A	Free	Trel-H	HDT	Free	Trel-H	Trel-A	G - SWS	F
G - SWS	Trel-H	Free	Trel-A	HDT	Free	Trel-A	Trel-H	G - SWS	F
G - SWS	Trel-H	Free	Trel-A	HDT	Free	Trel-A	Trel-H	G - SWS	F
G - SWS	Trel-H	Free	Trel-A	HDT	Free	Trel-A	Trel-H	G - SWS	F
G - SWS	Trel-H	Free	Trel-A	HDT	Free	Trel-A	Trel-H	G - SWS	F
G - SWS	Trel-H	Free	Trel-A	HDT	Free	Trel-A	Trel-H	G - SWS	F
G - SWS	Trel-H	Free	Trel-A	HDT	Free	Trel-A	Trel-H	G - SWS	F
G - SWS	Trel-H	Free	Trel-A	HDT	Free	Trel-A	Trel-H	G - SWS	F
G - SWS	Trel-H	Free	Trel-A	HDT	Free	Trel-A	Trel-H	G - SWS	F
G - SWS	G	G	G	G	G	G	G	G - SWS	F

Figure 21. Trial layout at Bellenden Ker. Datum trees are surrounded by guard trees, while the central datum row consists of ultra-high density spaced trees (HDT). Trees propagated as grafts or cuttings are colour coded according to the legend to the top right. Trel-A: trellised with angled branches; Trel-H: trellised with horizontal branches; Free: free standing trees.



Figure 22. Jackfruit demonstration trial.

In the trellised treatments, four support wires were positioned at heights of 80, 120, 160, and 200 cm from the ground. The free-standing trees (Free), by contrast, were self-supporting.

For the central leader, angled branch training (Trel-A), suitable branches were selected, bent, and attached to the trellis wires at a 45° angle using rubber ties. In the central leader, horizontal branch training system (Trel-H), branches were selected and attached horizontally to the trellis wires with rubber ties. In both systems, the central leader serves as the main component of the tree's scaffolding architecture.

For the free-standing trees, branches were pruned at the same time as those on the trellised trees, but the branches were allowed to follow their natural growth pattern.

The trellis system used 3.6 m long concrete posts with 10 mm pre-drilled holes spaced every 20 cm, starting 70 cm from the bottom of the post. The posts were installed at a depth of 0.9 to 1 m. Wires were attached to the posts with galvanized eyebolts and to galvanized anchors with hook and eye turnbuckles, allowing for tensioning as needed.

For the ultra-high-density row (figure 26), four inter-row tree spacings were evaluated: 1, 1.5, 2, and 2.5 m. Three plots of four trees each were established for each planting density, totalling 12 trees per density (n = 12). The plots were randomized throughout the row, and the trees were left untrained, except for the main leader branch, which was attached to the trellis wire for structural stability.



Figure 23. Horizontal tree branch training.



Figure 24. Angular tree branch training

Agronomical inputs

At the time of planting, trees were tied to the first trellis wire to protect them from wind or other damage. Subsequently, after trees had grown higher than the top trellis wire (200 cm), they were trimmed back to the height of the wire.

At the time of planting, 70 g per tree of Nitrophoska, a nitrogen, phosphorus, and potassium-based compound fertiliser, was incorporated into the topsoil. The application gradually increased to broadcasting 300 g per plant every six to eight weeks by the third year after planting. Occasionally, other nitrogen, phosphorus, and potassium-based compound fertilisers were used as substitutes for Nitrophoska. The grower occasionally added 5 litres of molasses through the fertigation system. Foliar fertilisers were applied every three to four months throughout the trial to maintain trace element levels. Herbicides, insecticides, and preventive fungicides were used in accordance with commercial farm practices. Irrigation was provided through an irrigation system, with schedules adjusted based on weather conditions.

Measurements and data collection

Soil moisture percentage was monitored using capacitance probes installed at depths of 20, 40, 60, 80, 100, and 120 cm. Measurements were taken at 30-minute intervals. For simplicity, the mean monthly soil moisture percentages from March 2023 and January 2024 were determined for depths of 20 cm (shallow), 80 cm (mid-profile), and 120 cm (deep) (figure 27).

Tree heights and trunk diameters were measured on 29 July 2022, and 6 January, 5 May, 18 July, and 20 November 2023 for the high density spaced trees. These dates correspond to approximately 8, 14, 18, 20, and 24 months after planting for the grafted trees, and 3, 9, 13, 15, and 19 months after planting for the cuttings.

For the ultra-high-density row, tree heights and trunk diameters were measured on 29 July 2022, and 6 January, 5 May, and 20 November 2023, corresponding to approximately 5, 11, 14, and 20 months after planting. Trunk diameters were also measured on these dates, with the exception of 29 July 2022.

Tree height was measured from the base of the trunk at ground level to the apex of the canopy. Trunk diameter was measured at 20 cm above ground level. The trunk cross-sectional area (TCSA) was subsequently estimated using the following formula: TCSA = $\pi(radius)^2$. The rate of TCSA expansion was determined by considering the days between each measurement. Since trees were topped once they have reached the top trellis wire, trunk cross-sectional area may be a better reflection of tree vigour in this case.

In July and November 2023, trees in the high density spaced rows were also monitored for flower and fruit emergence. The percentage of trees with flowers or fruit was subsequently determined.

Data analyses

Where applicable, the analysis of variance (ANOVA) was used to test the significance of differences for each variable. Fisher's least significant difference (LSD) test was used to identify significant differences between means at $P < 0.05$. Significant differences between variables are indicated with different letters in the figures. Where no letters appear in the figure, no significant differences were found between variables at the specific timepoint.

Results

Soil moisture

The soil profile at Bellenden Ker exhibited diverse water distribution characteristics, with the topsoil (20 cm) tending to dry out more rapidly, while deeper soil layers (80 cm and especially 120 cm) retained moisture for longer periods (figure 25). Throughout the year, soil moisture content at Bellenden Ker generally ranged between 15-20% at 20 cm, 20-25% at 80 cm, and 25-30% at 120 cm. In comparison, the soil moisture profile at South Johnstone (Figure 9) shows higher moisture content overall.

A rapid increase in soil moisture is evident around December 2023, a consequence of Cyclone Jasper impacting the region. Despite Bellenden Ker's historically high annual rainfall, the sandy soil resulted in lower average soil moisture levels among the sites studied. These disparities underscore the importance of considering soil properties when developing irrigation schedules for jackfruit trees.

Understanding the water retention capabilities and distribution patterns of different soil types is crucial for optimising irrigation practices. Given the shallow root system of juvenile trees at Bellenden Ker, it is important to irrigate more frequently during dry spells since the shallow soil layer dries out quickly. Proper irrigation scheduling that accounts for the site's specific soil characteristics will help ensure the optimal growth and health of jackfruit trees.

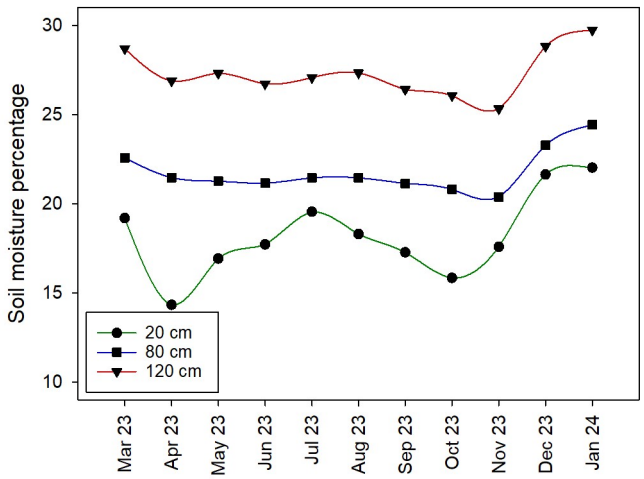


Figure 25. Mean monthly soil moisture percentage at Bellenden Ker from March 2023 to January 2024 at depths of 20, 80 and 120 cm.

Tree growth

The Bellenden Ker site contained trees with various training systems, propagation types, and planting densities, planted at different times. The tree growth measurement results (height, trunk cross-sectional area, and trunk cross-sectional area expansion rate) in the figures below compare:

1. Training systems for trees propagated as cuttings (figures 26, 29, and 32).

- Training systems for trees propagated as grafts (figures 27, 30, and 35).

2. Different ultra-high density tree spacings (figures 28, 31 and 37).
3. Propagation types (cuttings or grafts) for trees trained with different branch training techniques (figures 34, 35, and 36).
4. Additionally, to compare growth characteristics between propagation types and planting densities, trunk cross-sectional expansion rate was assessed across these parameters (figure 38).

Tree height development

For trees propagated from cuttings, no significant differences in tree heights were observed between those with horizontal or angled branch training and the free-standing trees at any measurement date from three to 19 months after planting (figure 26). All treatments exhibited significant tree growth over time.

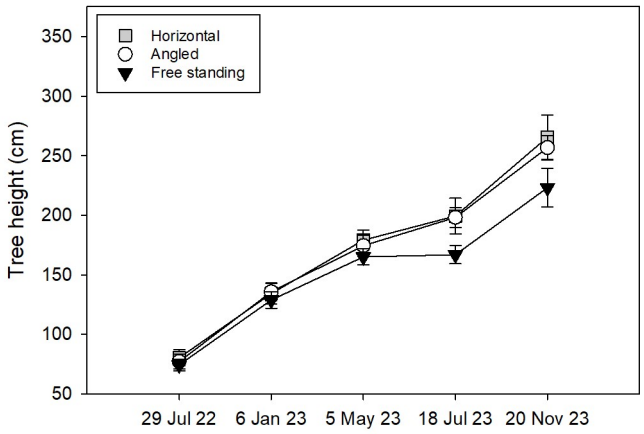


Figure 26. Tree height development of trellised trees trained with horizontal or angled branches or free-standing trees, propagated from cuttings, for a period of 19 months after planting (mean ± SE).

For trees propagated from grafts, those trained with angled branches exhibited greater heights than both the horizontally trained and free-standing trees from eight months to 18 months after planting, while the horizontally trained trees had greater heights than the free-standing trees during the same period (figure 27). By 20 months after planting, the free-standing trees were significantly shorter than both the angled and horizontally trained trees, and at two years after planting, the angled trained trees were taller than the free-standing trees. Note, the effect of tree topping at the top wire after 5 May 2023 is observable in terms of reduced tree heights.

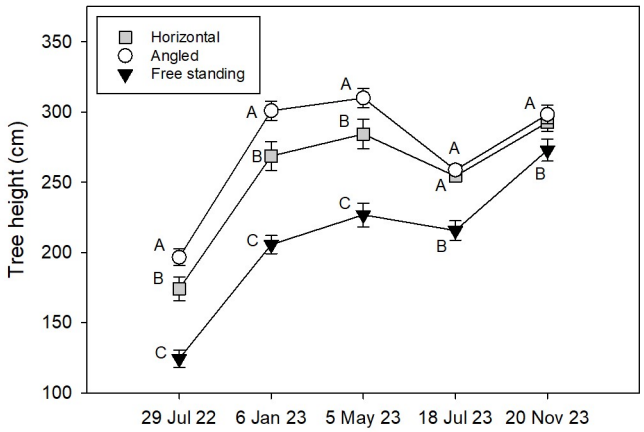


Figure 27. Tree height development of trellised trees trained with horizontal or angled branches or free-standing trees, propagated as grafts, for a period of 24 months after planting. For each measurement date, different letters represent significant differences among tree training treatments ($P < 0.05$; mean ± SE).

For seedlings planted at high density, no significant differences in tree height among the four different inter-tree spacings were observed throughout the measurement period (figure 28).

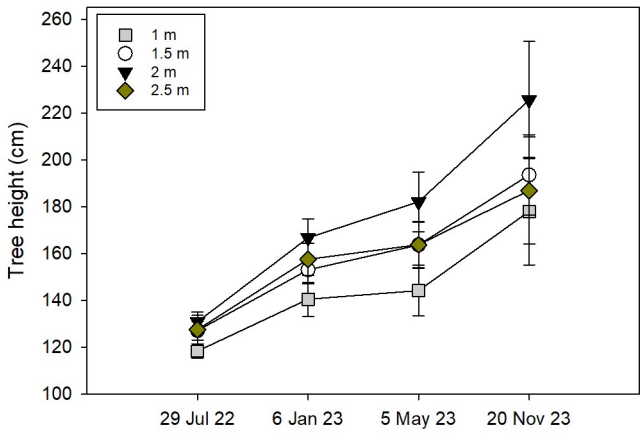


Figure 28. Tree height development over a period of 21-months after planting of jackfruit seedling trees at ultra-high density inter-tree spacings of 1, 1.5, 2 or 2.5 m (mean ± SE).

Trunk cross-sectional area

For the trees propagated from cuttings, the trunk cross-sectional areas for all training systems increased gradually over time (figure 29). By 19 months after planting, the free-standing trees had a greater trunk cross-sectional area compared to the angled trained trees.

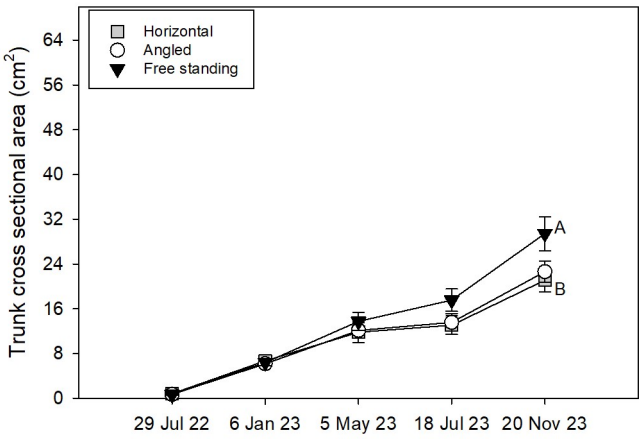


Figure 29. Trunk cross-sectional area development of trellised trees trained with horizontal or angled branches or free-standing trees, propagated from cuttings, for a period of 19 months after planting. Different letters represent significant differences among tree training treatments (P < 0.05; mean ± SE).

For the grafted trees, trunk cross-sectional areas were greater for the horizontally and angled trained trees compared to the free-standing trees from the initial measurement at eight months after planting until around 18 months after planting (figure 30). Subsequently, until two years after planting, the free-standing trees continued to have a reduced trunk cross-sectional area compared to the angled trained trees.

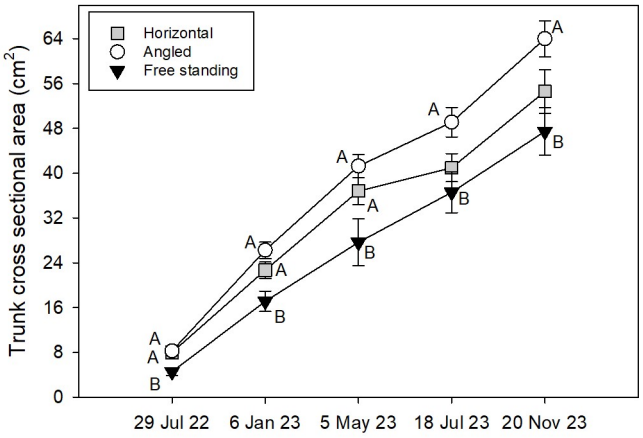


Figure 30. Trunk cross-sectional area development of trellised trees trained with horizontal or angled branches or free-standing trees, propagated as grafts, for a period of 19 months after planting. Different letters represent significant differences among tree training treatments (P < 0.05; mean ± SE).

No significant differences among the inter-tree spacings were observed throughout the measurement period trunk cross-sectional area within the first 21 months after planting (figure 31). This suggests that under ultra-high planting density, slight variations in tree spacing during this period are unlikely to affect tree growth.

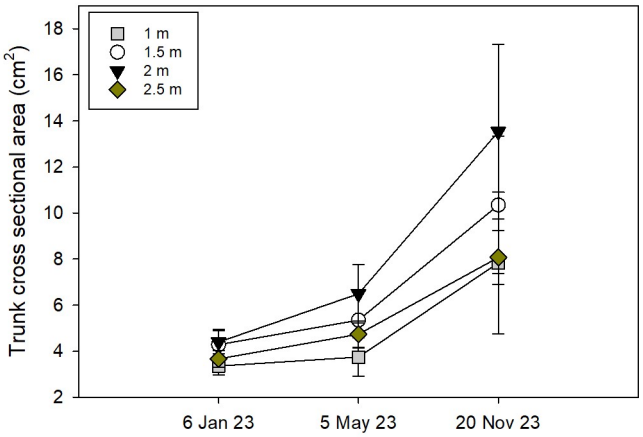


Figure 31. Trunk cross-sectional area development over a period of 21-months after planting of jackfruit seedling trees at ultra-high density inter-tree spacings of 1, 1.5, 2 or 2.5 m (mean ± SE).

Trunk cross sectional-area expansion rate

In terms of the rate of trunk cross-sectional area expansion, no significant differences were observed among training systems for the trees propagated from cuttings (figure 32).

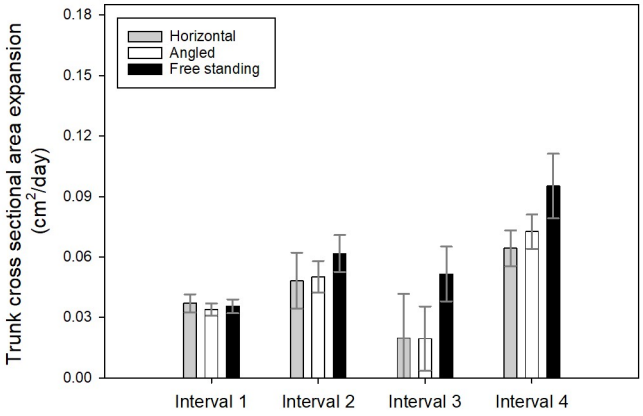


Figure 32. Trunk cross-sectional area expansion rate of trellised trees trained with horizontal or angled branch training or free-standing trees, propagated from cuttings, for a period in the first 19 months after planting. Intervals 1, 2, 3, and 4 represent the periods between measurements: 29 July 2022 to 6 January 2023 (23 weeks), 6 January to 5 May 2023 (17 weeks), 5 May to 18 July 2023 (10 weeks), and 18 July to 20 November 2023 (17 weeks), respectively (mean ± SE).

Similarly to the cuttings, no significant differences were observed among the training systems for the trees propagated as grafts (Figure 33). The grafted trees tended to exhibit higher rates of trunk growth compared to the cuttings. This difference can be partially attributed to the rapid diameter growth of the rootstock, as well as the type of root development—grafted trees typically develop both a taproot and shallow roots, whereas trees grown from cuttings only develop shallow roots. Additionally, the difference may be partly due to tree age, as the grafted trees were planted five months earlier than the cuttings.

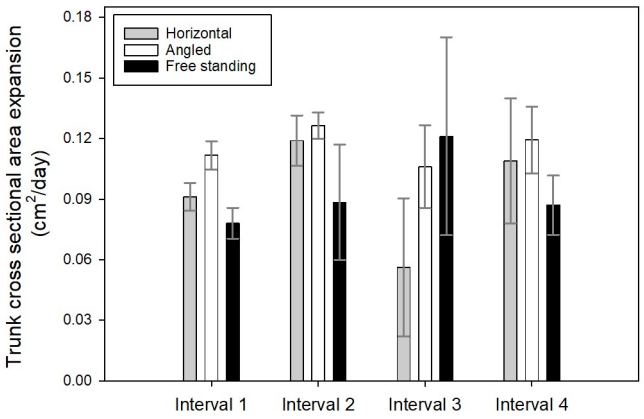


Figure 33. Trunk cross-sectional area expansion rate of trellised trees trained with horizontal or angled branch training or free-standing trees, propagated as grafts, for a period in the first 19 months after planting. Intervals 1, 2, 3, and 4 represent the periods between measurements: 29 July 2022 to 6 January 2023 (23 weeks), 6 January to 5 May 2023 (17 weeks), 5 May to 18 July 2023 (10 weeks), and 18 July to 20 November 2023 (17 weeks), respectively (mean ± SE).

In a detailed comparison of trunk cross-sectional area development between trees propagated from cuttings and those grafted, across three high density spaced training systems, a trend emerged: grafted trees exhibit a greater rate of trunk growth early on, with the cuttings catching up later to some extent (figures 34, 35 and 36). This is likely related to the root development and tree age, as the grafts were planted several months before the cuttings. This effect varied between the training systems and was most pronounced in trees trained with angled branches, where grafted trees maintained a greater rate of trunk growth throughout the measurement period (figure 35). For horizontally trained trees, grafted trees exhibited greater trunk growth than cuttings for the first two measurement intervals (figure 34). In contrast, for the free-standing trees, this effect was only significant for the first interval (figure 36).

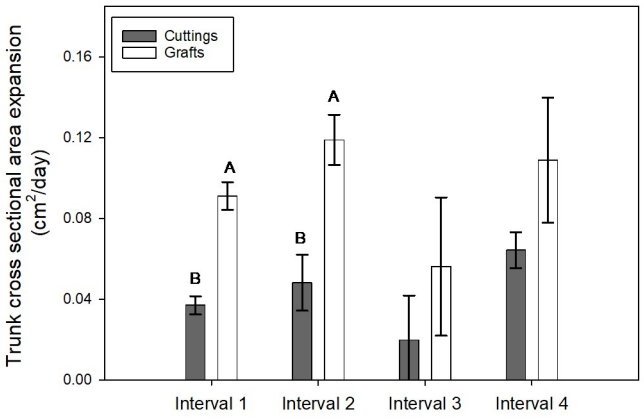


Figure 34. Trunk cross-sectional area expansion rate of trellised trees with horizontal branch training, propagated form cuttings or grafts. Different letters represent significant differences among cuttings and grafts ($P < 0.05$; mean ± SE). Intervals 1, 2, 3 and 4 represent the periods between measurements, thus, 29 July 2022 to 6 January 2023 (23 weeks), 6 January to 5 May 2023 (17 weeks), 5 May to 18 July 2023 (10 weeks), and 18 July to 20 November 2023 (17 weeks), respectively. Different letters represent significant differences among propagation types ($P < 0.05$; mean ± SE).

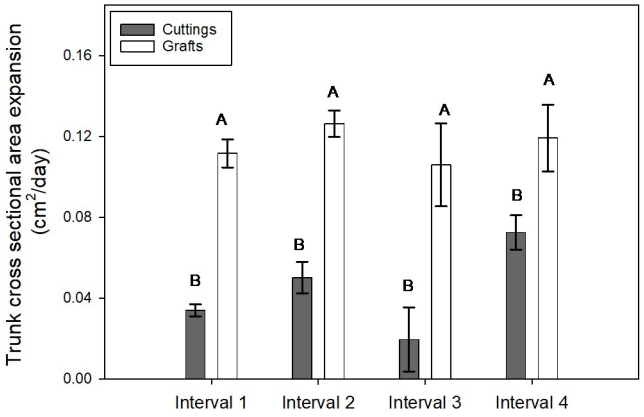


Figure 35. Trunk cross-sectional area expansion rate of trellised trees with angled branch training, propagated form cuttings or grafts. Different letters represent significant differences among cuttings and grafts (P < 0.05; mean ± SE). Intervals 1, 2, 3 and 4 represent the periods between measurements, thus, 29 July 2022 to 6 January 2023 (23 weeks), 6 January to 5 May 2023 (17 weeks), 5 May to 18 July 2023 (10 weeks), and 18 July to 20 November 2023 (17 weeks), respectively Different letters represent significant differences among propagation types (P < 0.05; mean ± SE).

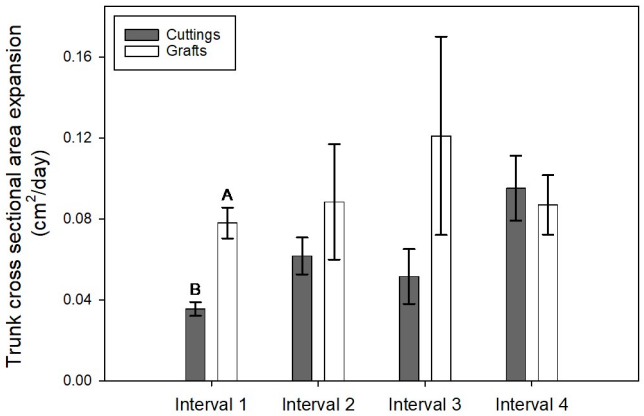


Figure 36. Trunk cross-sectional area expansion rate of free-standing trees, propagated form cuttings or grafts. Different letters represent significant differences among cuttings and grafts (P < 0.05; mean ± SE). Intervals 1, 2, 3 and 4 represent the periods between measurements, thus, 29 July 2022 to 6 January 2023 (23 weeks), 6 January to 5 May 2023 (17 weeks), 5 May to 18 July 2023 (10 weeks), and 18 July to 20 November 2023 (17 weeks), respectively. Different letters represent significant differences among propagation types (P < 0.05; mean ± SE).

No significant differences in the rate of trunk cross-sectional area development occurred between the tree spacings within the high-density trial for both measurement intervals (figure 37). However, the trunk expansion rate generally increased during the second interval.

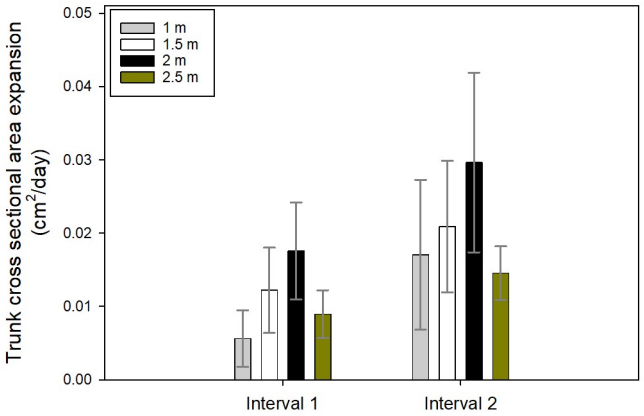


Figure 37. Rate of trunk cross-sectional expansion for the 21-months after planting of jackfruit seedling trees at ultra-high density inter-tree spacings of 1, 1.5, 2 or 2.5 m. Intervals 1 and 2 represent the periods between measurements, thus, 6 January to 5 May 2023 (17 weeks), and 5 May to 20 November 2023 (28 weeks), respectively (mean ± SE).

Among the types of propagation used, and irrespective of tree training or planting density, grafted trees exhibited the greatest rate of trunk cross-sectional area expansion during the two measurement intervals from 6 January to 5 May 2023 (17 weeks), and from 5 May to 20 November 2023 (28 weeks) (figure 38). In contrast, the seedlings planted at high density had the slowest rate. Considering the different planting timings, this was likely affected by tree age to some extent. However, these results also suggest a significant impact of planting material on early jackfruit tree vegetative development.

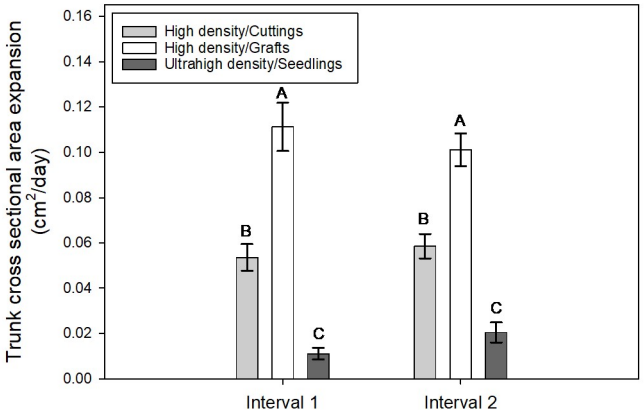


Figure 38. Trunk cross-sectional area expansion rate of high density spaced trees propagated from cuttings or grafts, and ultra-high density planted trees propagated from seedlings, measured over the first 19, 24, and 21 months after planting, respectively. Different letters represent significant differences among the types of plants ($P < 0.05$; mean ± SE). Intervals 1 and 2 represent the periods between 6 January to 5 May 2023 (17 weeks), and 5 May to 20 November 2023 (28 weeks), respectively. Values represent means across the different training systems and tree spacing for the high and ultra-high density treatments, respectively. Different letters represent significant differences among the planting density-propagation type combinations ($P < 0.05$; mean ± SE).

Fruiting and flowering status

Grafted trees began showing signs of flowering and fruiting earlier than those propagated from cuttings, likely due to the grafts being planted approximately five months earlier (figure 39). By July 2023, 20 months after planting, a notable proportion of grafted trees across all branch training systems had flowers and/or fruit: 25% for free-standing trees, 38% for trellised trees with angled branch training, and 44% for trellised trees with horizontal branch training. By November 2023, 24 months after planting, these proportions had increased to 75% for free-standing trees and 100% for both angled and horizontally trained branch trees (figure 40).

In contrast, none of the trees propagated from cuttings showed signs of flowering or fruiting by July 2023 (figure 39). By November 2023, 19 months after planting, these proportions had increased to 31% for both free-standing trees and those trellised with horizontal branches, and 38% for trellised trees with angled branches (figure 40).

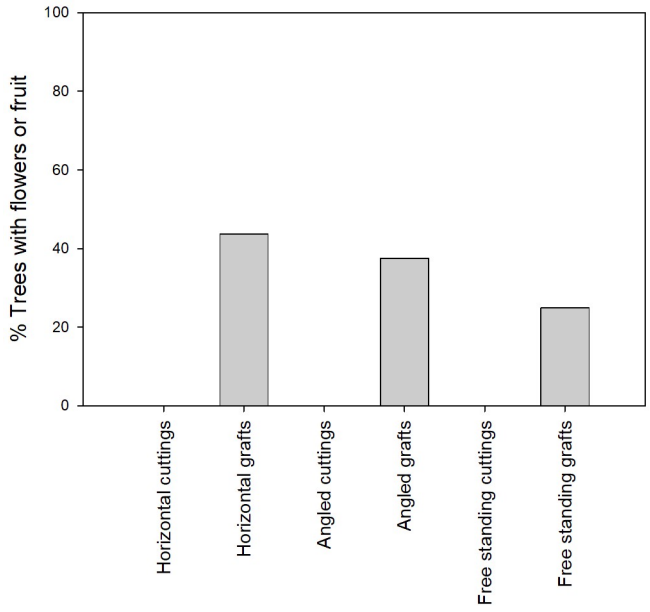


Figure 39. Percentage of trees with either flowers or fruit present on 18 July 2023 for each branch training system, comparing trees propagated from cuttings and grafts.

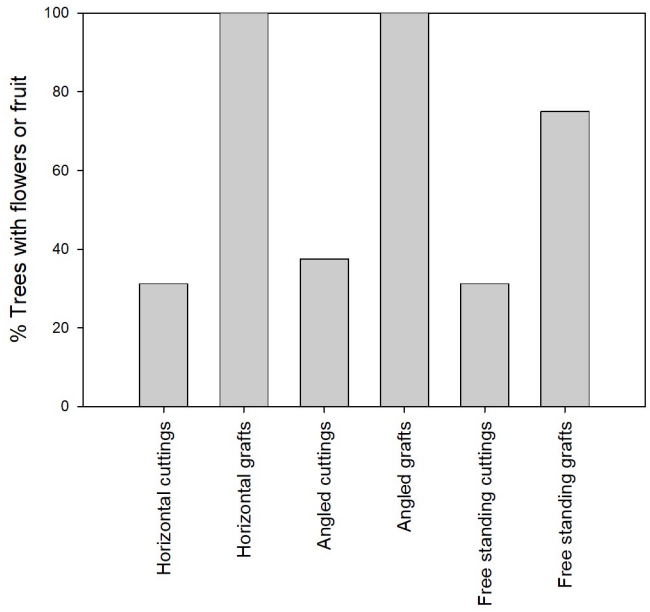


Figure 40. Percentage of trees with either flowers or fruit present on 20 November 2023 for each branch training system, comparing trees propagated from cuttings and grafts.



Figure 41. Trellised 2 years old grafted tree with young fruit.



Figure 42. Fruit on a 24 months old cutting tree.

Discussion and conclusions

The trials conducted at the Bellenden Ker site provided insights into the growth dynamics of young jackfruit trees propagated from cuttings, grafts, and seedlings under various training systems and planting densities. The sandy loam soil, combined with the site's high annual rainfall, significantly influenced soil moisture levels. However, due to the age of the trials, it is not possible to draw definitive conclusions regarding the impact of soil moisture on tree growth for this report.

For trees propagated from cuttings, the initial growth was not significantly affected by trellising and branch training. In contrast, grafted trees exhibited a more pronounced response to branch training practices and trellising. Specifically, angled branch training on trellised trees enhanced early growth compared to free-standing trees, making it a viable option for growers seeking vigorous early growth in jackfruit trees, or conversely, employing horizontal branch training may reduce early vegetative vigour.

Due to the variation in planting times between cuttings and grafts, it is challenging to draw strong conclusions regarding differences in growth rates. Nonetheless, the results suggest that grafted jackfruit trees establish more vigorous early growth than those propagated from cuttings. Over time, cuttings seem to catch up with grafted trees in terms of growth rate.

For seedlings planted at ultra-high density, slight variations in tree spacing had a limited impact on early growth. However, these seedlings initially grew slower than cuttings and grafts planted at less dense tree spacings. This indicates that while ultra-high density planting does not significantly affect growth variations due to spacing, it may influence the overall growth rate compared to more traditionally spaced plantings.

Regarding reproductive development, while the results should be interpreted with caution due to differences in planting times, they suggest that trees propagated from grafts may begin fruiting slightly earlier (figure 41) than those propagated from cuttings (figure 42). Further work is needed to assess if this trend continues when jackfruit trees approach maturity and full production.

Site 3: Mutchilba

Site description

The Hilltop site near Mutchilba is situated on a commercial farm operated by Manbulloo Ltd (figure 43). The soil at this site is characterised as Dimbulah red mix with a sandy clay texture (Enderlin, 1997). 'Rajang' jackfruit seedlings were planted on 8 October 2021. These trees were either trellised using different branch training techniques or left free-standing, as detailed below, and spaced at 3 m between trees and 8.71 m between rows.

Three training systems on trellised trees, in addition to free-standing trees, were trialled (figure 44). The trellis system used treated pine poles, consisting of two 150 mm x 4.5 m end poles and five 100 mm x 4.5 m inner poles per row. The wires were spaced 0.7 m apart, starting at 0.7 m above the ground, with the top wire being at 2.8 m. The trial consisted of two rows, with guard trees on the ends of each row. The first row contained 26 free-standing trees (n = 26), while the second row was split into three replicates with three-tree plots of each trellised training system randomised, establishing nine trees of each training system (n = 9).

The branch training systems for the trellised trees were:

1. Central Leader with Horizontally Trained Branches: This system involved selecting suitable branches and bending/attaching them horizontally with a rubber tie to the trellis wires.
2. Central Leader Removed at Each Wire with Horizontally Trained Branches: In this system, the central leader was cut at every wire, and a new shoot was selected to become the new central leader. At each wire, two branches were selected and trained horizontally on the wire, opposite to the central leader.
3. Central Leader with Angled Trained Branches: This system involved selecting suitable branches and bending/attaching them at a 45° angle with a rubber tie to the trellis wire.
4. Free-Standing Trees: For free-standing trees, branches were pruned at the same time as the trellised trees, but they were allowed to follow their natural growth pattern without additional training.



Figure 43. Jackfruit demonstration trial.



Figure 44. Trial layout at Mutchilba. Row 1 consists of free-standing jackfruit trees, whereas row 2 consists of trellised trees.



Figure 45. Soil moisture probe installed in the trellised trial.

Agronomical inputs

Herbicides, insecticides, and preventive fungicides were applied in accordance with standard commercial farm practices. Irrigation was provided through an irrigation system, with the schedule adjusted based on prevailing weather conditions.

A nutrition program similar to that used for young mango trees was applied to support the juvenile phase of the jackfruit trees. At planting, 200 g per tree of Superphosphate was used, with half incorporated into the bottom of the hole and the other half mixed with the soil used to fill around the plant. Additionally, 500 g of gypsum was spread around the base of each tree. The trees were then left for about one to two months to acclimate to the new environment until a new flush appeared, before starting the continuous fertiliser program. The fertiliser program was used for two-and-a-half years, with slight adjustments in grams per tree depending on the growth rate.

The main fertilisers used were:

Diamond 19 Carat (19% N; 8.3% P; 15.8% K; 0.8% S; 1.2% Mg; 0.05% Fe; 0.025% Mn; 0.01% B; 0.008% Zn; 0.006% Cu; 0.004% Mo); Urea S; and Mono-Ammonium Phosphate (MAP). Additional trace elements in the form of zinc sulphate, iron sulphate, copper sulphate, and boron were added, along with gypsum. The application schedule was as follows:

First Month: 75 g of Diamond 19 Carat, 10 g of each zinc, iron, and copper sulphates, and 3 g of boron were applied. This was repeated every other month (months 3, 5, 7, and so on). Additionally, 500 g of gypsum was added in the first month and every four months thereafter (months 5, 9, 13, and so on).

Second Month: 50 g of Urea S, 30 g of MAP Tech, 10 g of zinc sulphate, and 3 g of boron were added. This was repeated every other month thereafter (months 4, 6, 8, and so on).

Measurements and data collection

Soil moisture percentage was monitored using capacitance probes installed at depths of 20, 40, 60, 80, 100, and 120 cm (figure 45). Measurements were taken at 30-minute intervals. For simplicity, the mean monthly soil moisture percentages from March 2023 and January 2024 were determined for depths of 20 cm (shallow), 80 cm (mid-profile), and 120 cm (deep) (figure 48).

Tree heights and trunk diameters were measured on 28 July 2022, and 25 January, 3 May, 15 June and 15 November 2023, approximately 9, 15, 19, 20 and 25 months after planting.

Tree height was measured from the base of the trunk at ground level to the apex of the canopy. Trunk diameter was measured at 20 cm above ground level. The trunk cross-sectional area (TCSA) was subsequently estimated using the following formula: TCSA = $\pi(radius)^2$. The rate of TCSA expansion was determined by considering the days between each measurement. Since trees were topped once they reached the top trellis wire, trunk cross sectional area instead of tree height may be a better reflection of tree growth in this case.

In June and November 2023, trees were also monitored for flower and fruit emergence. The percentage of trees with flowers or fruit was subsequently determined.

Data analysis

Where applicable, the analysis of variance (ANOVA) was used to test the significance of differences for each variable. Fisher's least significant difference (LSD) test was used to identify significant differences between means at $P < 0.05$. Significant differences between variables are indicated with different letters in the figures. Where no letters appear in the figure, no significant differences were found between variables at the specific timepoint.

Results

Soil moisture

The soil moisture distribution at the Mutchilba site, although relatively variable across the depths assessed, generally ranged between 24% and 34% (figure 46). The shallow soil, in particular, maintained a consistent soil moisture profile year-round. In contrast, the 80 cm and 120 cm layers exhibited lower moisture levels during the dry season, with a rapid increase around December. The impacts of Cyclone Jasper were notably observed in the deeper soil profile.

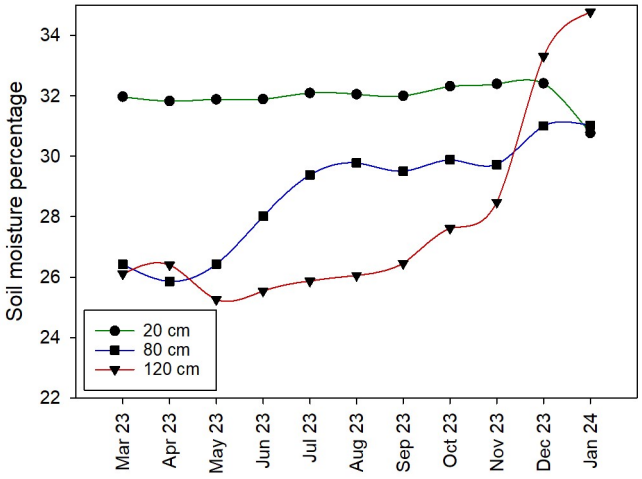


Figure 46. Mean monthly soil moisture percentage from March 2023 to January 2024 at depths of 20, 80 and 120 cm.

Tree growth

The evaluations at the Mutchilba site involved trees with different branch training systems. Therefore, the figures below compare tree height (figure 47), trunk cross-sectional area (figure 48), and trunk cross-sectional area expansion rate (figure 49) across the different training systems.

Tree height development

By nine months after planting, the tree height of the central leader cut at each wire and branches horizontally trained, was significantly reduced compared to all other training systems (figure 47). This trend persisted for the next six months. By approximately 19 months post-planting, the central leader-trained trees continued to show reduced heights compared to the central leader-trained trees with branches trained at an angle. This pattern remained at around 21 and 25 months after planting, with the central leader-trained trees with angled branches also exhibiting greater heights compared to the free-standing trees at these two measurement dates.

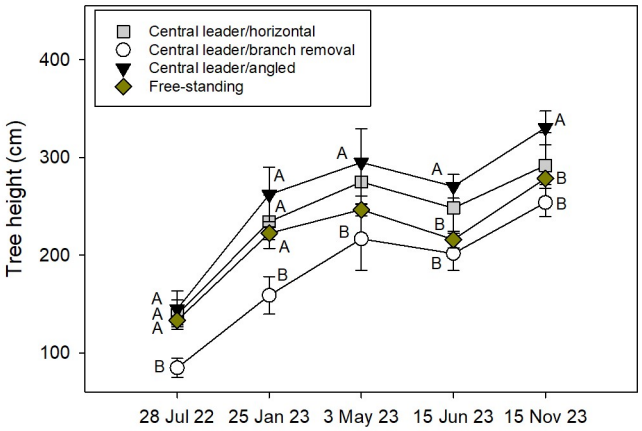


Figure 47. Tree height development for a period within the first two years after planting of jackfruit trees propagated from seedlings with either a central leader and horizontally trained branches, a central leader cut at each wire and branches horizontally trained at each wire, a central leader and branches trained with an angle, or free-standing trees. The different letters represent significant differences among tree training treatments ($P < 0.05$; mean ± SE).

Trunk cross-sectional area

At the first measurement, around 15 months after planting, the trees trained with central leader cut at each wire and branches horizontally trained, had a reduced cross-sectional area compared to all other trees (figure 48). By around 19 months after planting, these trees continued to exhibit a reduced trunk cross-sectional area compared to free-standing trees. This trend persisted through subsequent measurements, concluding at around 25 months after planting. Additionally, for the final two measurements, the central leader-trained trees with angled branches had a higher trunk cross-sectional area than the trees trained with central leader cut at each wire and branches horizontally trained.

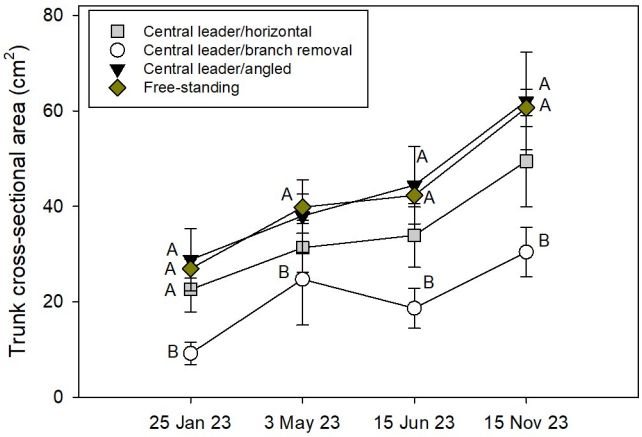


Figure 48. Trunk cross-sectional area (TCSA) development for a period within the first two years after planting of jackfruit trees propagated from seedlings with either a central leader and horizontally trained branches, a central leader cut at each wire and branches horizontally trained at each wire, a central leader and branches trained with an angle, or free-standing trees. The different letters represent significant differences among tree training treatments ($P < 0.05$; mean ± SE).

Trunk cross-sectional area expansion rate

No significant differences were observed in the rate of trunk cross-sectional area expansion throughout the measurement period, regardless of tree training method (figure 49). Additionally, the rate of trunk expansion remained relatively consistent over time.

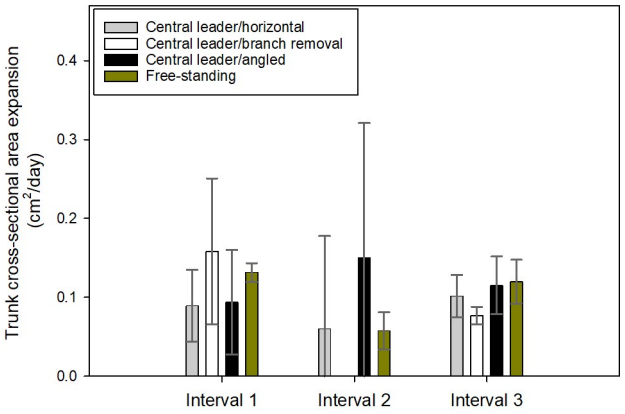


Figure 49. Trunk cross-sectional area (TCSA) expansion rate for a period within the first two years after planting of jackfruit trees propagated from seedlings with either a central leader and horizontally trained branches, with central leader cut at each wire and branches horizontally trained, a central leader and branches trained with an angle, or free-standing trees. Intervals 1, 2 and 3 represent the periods between measurements, thus, 25 January to 3 May 2023 (14 weeks), 3 May to 15 July 2023 (10 weeks), and 15 July to 15 November 2023 (17 weeks), respectively (mean ± SE).

Fruiting and flowering status

A proportion of trees from each training system had flowers or fruit by June 2023 (figure 50). However, trees with central leaders and angled branches appeared to outperform the other training systems, especially those with central leader cut at each wire and branches horizontally trained. Central leader trees with horizontal branches and free-standing trees had intermediate and similar fruiting status at this time.

By November 2023, the fruiting status of the central leader trees with angled branches remained more or less stagnant compared to June, while the proportion of trees with flowers or fruit increased for all other training types, catching up with the trees with angled branches (figure 51).

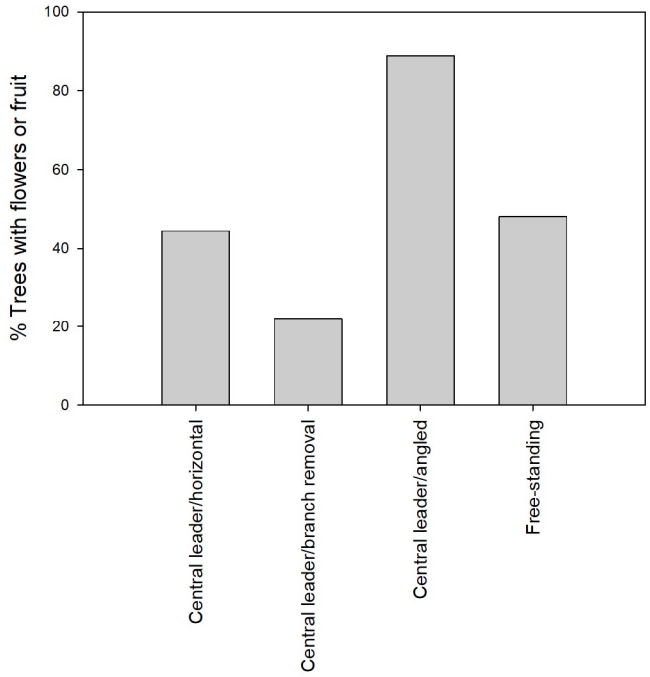


Figure 50. Percentage of trees with either flowers or fruit present on 15 June 2023 for each branch training system.

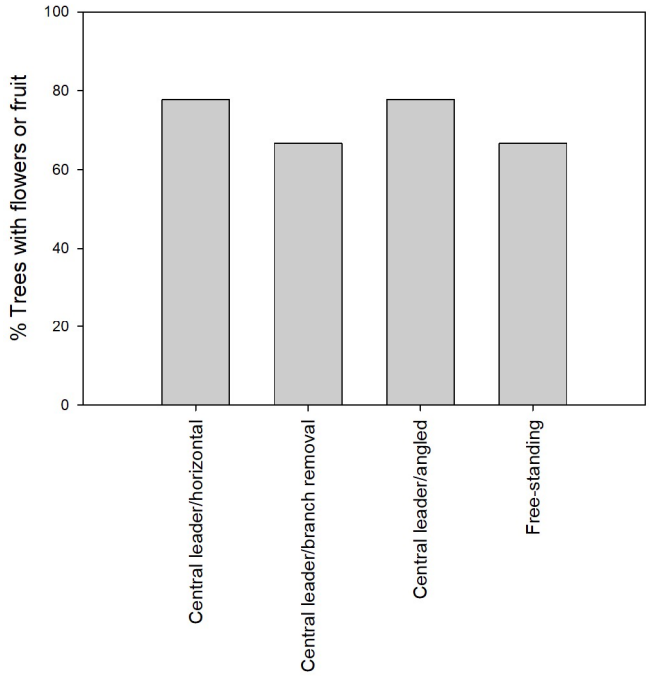


Figure 51. Percentage of trees with either flowers or fruit present on 15 November 2023 for each branch training system.

Discussion and conclusions

The research findings at the Mutchilba site offer several insights into the impacts of tree training systems on the growth and development of young jackfruit trees. Branch training systems significantly influenced tree height, with angled branch

training promoting better vertical growth compared to the other methods, specifically free-standing trees and those with central leader cut at each wire and branches horizontally trained.

Trunk cross-sectional area measurements further support the conclusion that the central leader with angled branches training system is effective in promoting early tree growth, while free-standing trees also showed good growth characteristics. In contrast, trees with central leader cut at each wire and branches horizontally trained exhibited reduced growth.

Regarding reproductive development, the central leader-trained trees with angled branches outperformed the other systems in terms of promoting early flowering or fruiting development, especially compared to those with central leader cut at each wire and branches horizontally trained. By November 2023, the fruiting status of the central leader trees with angled branches remained relatively stagnant compared to June, while the proportion of trees with flowers or fruit increased for all other training types, catching up with the trees with angled branches. This suggests that while angled branch training may provide an early advantage in reproductive development, other training systems eventually catch up.

In conclusion, the results suggest that single leader trellised tree training with angled branches could offer advantages in terms of early jackfruit tree growth and reproductive development. However, the eventual convergence of fruiting status across different training systems indicates that while initial growth advantages can be achieved through specific training methods, other systems may eventually provide similar outcomes. Further work is therefore required to assess tree growth beyond the first couple of years after orchard establishment.

Site 4: Townsville

Site description

The Laudham Park site near Townsville is situated on a commercial farm operated by Manbulloo Ltd. The site features a Kulburn soil, characterised by sandy loam to silty loam with a heavy clay subsoil (Murtha, 1975). 'Rajang' jackfruit seedlings were planted on 8 October 2021. These trees were either trellised using different branch training techniques or left free-standing, as detailed below. The distances between trees and rows, were 3 and 6 m, respectively. Approximately 16 of the original 54 treatment trees died or were in extremely poor condition and and were replaced in mid-December 2022. For the purposes of this report, data analysis and results will focus on the remaining 38 original trees.

Three training systems on trellised trees, in addition to free-standing trees, were trialled (figure 54). The trial consisted of two rows, with guard trees on the edges of each row, adjacent rows also contained guard trees. The first row was split into three replicates with three-tree plots of each trellised training system randomized, establishing nine trees of each training system (n = 9), the second row contained 26 free-standing trees (n = 26).

The branch training systems for the trellised trees were:

1. Central Leader with Horizontally Trained Branches: Involved selecting suitable branches and bending/attaching them horizontally with rubber ties to the trellis wires (figure 54).

- Central Leader Removed at Each Wire with Horizontally Trained Branches: Involved cutting the central leader at each wire and selecting a new shoot to become the new central leader. At each wire, two branches are selected and trained horizontally on the wire, each opposite to the central leader (figure 54).

2. Central Leader with Angled Trained Branches: Involved selecting suitable branches and bending/attaching them at a 45° angle with rubber ties to the trellis wire.
3. Free-Standing Trees: Tree branches were pruned at the same time as the trellised trees but were left to their normal growth pattern. For the free standing trees, the central leader was cut during pruning to promote branch growth in an almost horizontal direction, and shaping the tree as an “open vase“ form.

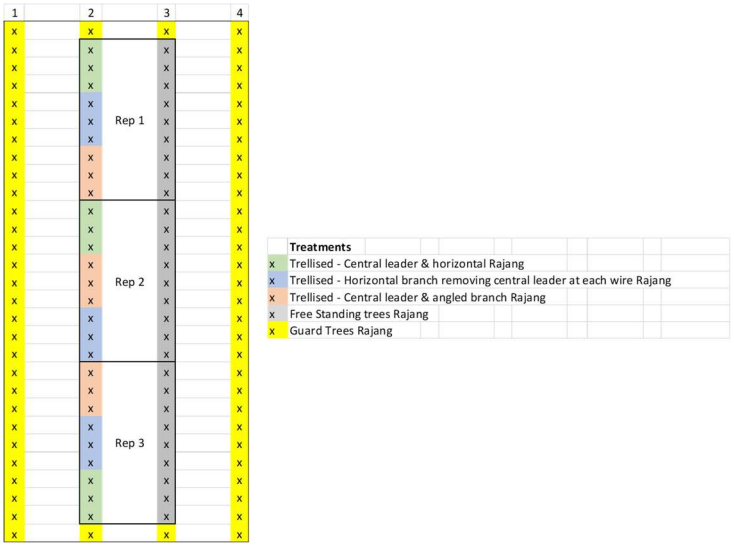


Figure 52. Trial layout at Townsville. Row 1 consists of trellised trees, whereas row 2 consists of free-standing trees.



Figure 53. Jackfruit demonstration trial.



Figure 54. Left tree central leader with horizontally trained branch. On the right, central leader removed at each wire with horizontally trained branch.

Agronomical inputs

The same agronomic inputs described for the Hilltop (Mutchilba) site were used at this site.

Measurements and data collection

Soil moisture percentage was monitored using capacitance probes installed at depths of 20, 40, 60, 80, 100, and 120 cm. Measurements were taken at 30-minute intervals. For simplicity, the mean monthly soil moisture percentages from March 2023 and January 2024 were determined for depths of 20 cm (shallow), 80 cm (mid-profile), and 120 cm (deep) (figure 59).

Tree heights and trunk diameters were measured on 9 November 2022, and 20 June and 22 November 2023, approximately 13, 20 and 25 months after planting.

Tree height was measured from the base of the trunk at ground level to the apex of the canopy. Trunk diameter was measured at 20 cm above ground level. The trunk cross-sectional area (TCSA) was subsequently estimated using the following formula: TCSA = $\pi(radius)^2$. The rate of TCSA expansion was determined by considering the days between each measurement.

In November 2023, trees were also monitored for flower and fruit emergence. The percentage of trees with flowers or fruit was subsequently determined.

Data analysis

Where applicable, the analysis of variance (ANOVA) was used to test the significance of differences for each variable. Fisher's least significant difference (LSD) test was used to identify significant differences between means at $P < 0.05$. Significant differences between variables are indicated with different letters in the figures. Where no letters appear in the figure, no significant differences were found between variables at the specific timepoint.

Results

Soil moisture

Generally, the soil moisture distribution at the Laudham Park site varied significantly between soil depths (figure 59). The topsoil profile remained relatively dry, typically below 30% moisture. In contrast, the deeper soil layers at 80 cm and 120 cm retained moisture for longer periods and consistently had a higher moisture content, usually staying above 40%. For the shallow profile, a decline in moisture was observed after October 2023, but it was refilled around December. This effect was also visible, albeit to a lesser extent, in the 80 cm profile The distribution of soil moisture across depths is likely influenced by the soil type, with the clay subsoil retaining moisture for longer, while the sandier or loamier topsoil dries out more quickly.

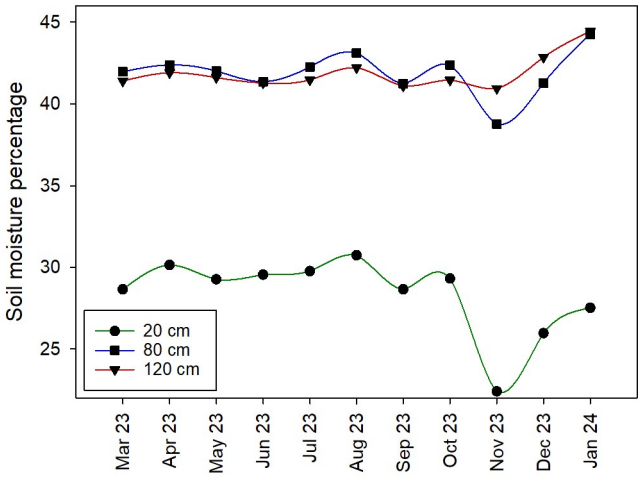


Figure 55. Mean monthly soil moisture percentage from March 2023 to January 2024 at depths of 20, 80 and 120 cm.

Tree growth

The evaluations at the Mutchilba site involved trees with different branch training systems. Therefore, the figures below compare tree height (figure 60), trunk cross-sectional area (figure 61), and trunk cross-sectional area expansion rate (figure 62) across the different training systems.

Tree height development

By thirteen months after planting, the height of free-standing trees was significantly reduced compared to those trained to a single leader with horizontally trained branches (figure 60). By approximately twenty months after planting, trees with a single leader and horizontally trained branches were taller than both those with angled branches and free-standing trees. Additionally, central leader cut at each wire and branches horizontally trained were also taller than free-standing trees. At the final measurement, taken twenty-five months after planting, free-standing trees exhibited the lowest heights.

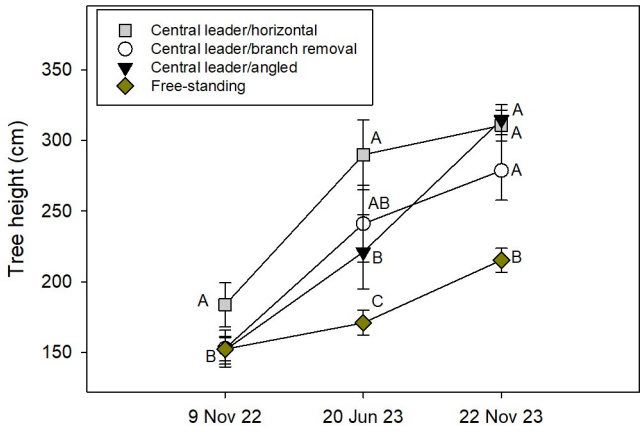


Figure 56. Tree height development for a period within the first 25 months after planting of jackfruit trees propagated from seedlings with either a central leader and horizontally trained branches, a central leader pruned and branches trained horizzontally, a central leader and branches trained with an angle, or free-standing trees. The different letters represent significant differences among tree training treatments ($P < 0.05$; mean ± SE).

Trunk cross-sectional area

At the initial measurement, around thirteen months after planting, trees trained to a single leader with horizontally trained branches showed a greater trunk cross-sectional area compared to other trees (figure 61). This trend persisted throughout the rest of the measurements, except at the final measurement when trunk cross-sectional areas of single leader trees with horizontally trained branches did not significantly differ from those with angled branches.

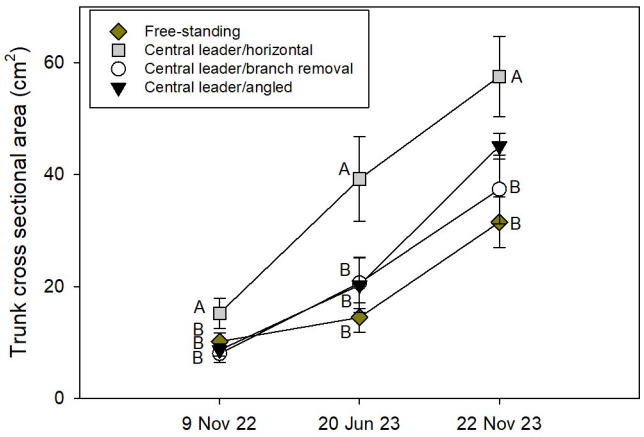


Figure 57. Trunk cross-sectional area development for a period within the first 25 months after planting of jackfruit trees propagated from seedlings with either a central leader and horizontally trained branches, central leader cut at each wire and branches horizontally trained, a central leader and branches trained with an angle, or free-standing trees. The different letters represent significant differences among tree training treatments ($P < 0.05$; mean ± SE).

Trunk cross-sectional expansion rate

During the first interval, from November 9, 2022, to June 20, 2023, trunk cross-sectional area expansion for trees with a single leader and horizontally trained branches was superior to all other trees (figure 62). However, no significant differences were observed in the rate of trunk cross-sectional area expansion during the second measurement interval.

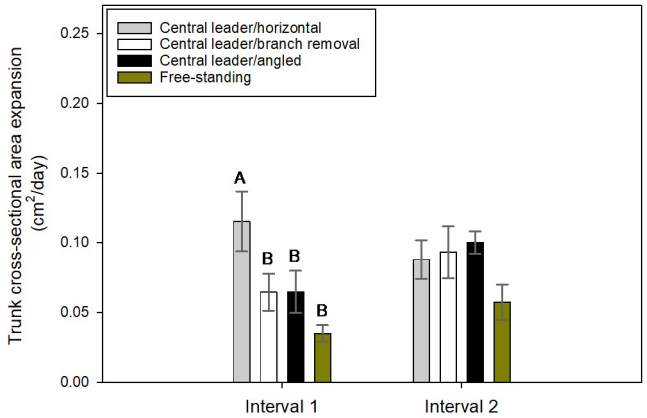


Figure 58. Trunk cross-sectional area (TCSA) expansion rate for a period within the first 25 months after planting of jackfruit trees propagated from seedlings with either a central leader and horizontally trained branches, central leader cut at each wire and branches horizontally trained, a central leader and branches trained with an angle, or free-standing trees. Intervals 1, 2 and 3 represent the periods between measurements, thus, 9 November 2022 to 20 June 2023 (31 weeks), and 20 June to 22 November 2023 (22 weeks), respectively.

Flowering and fruiting status

By November 2023, a proportion of trees from each training system had flowers and fruit present (figure 63). The extent varied, with central leader-trained trees with horizontally trained branches having the lowest proportion of trees with flowers or fruit. Central leader cut at each wire and branches horizontally trained exhibited intermediate proportions. Central leader-trained trees with angled branches and free-standing trees had a slightly higher proportion of trees with flowers or fruit by that time.

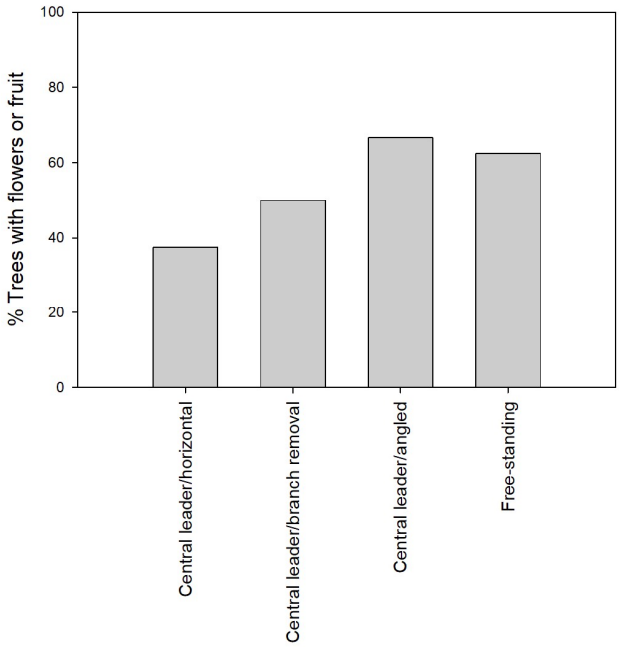


Figure 59. Percentage of trees with either flowers or fruit present on 22 November 2023 for each branch training system.

Discussion and conclusions

The findings at the Laudham Park site provide insights into the impacts of different tree training systems on the growth and development of young 'Rajang' jackfruit trees.

Free-standing trees appeared to be at a disadvantage at an early stage of tree development, as their height and trunk cross-sectional area were reduced especially compared to trees trained to a central leader with horizontally trained branches. Trellising, regardless of the branch training strategy, generally promoted vertical growth within the first 25 months after planting. Initially, trunk cross-sectional area development was improved by training trees to a central leader with horizontal branch training. The larger trunk cross-sectional area suggests that these trees had a stronger structural foundation, potentially supporting better growth and fruiting potential in the long term. Although the growth rates for the other training systems appeared to catch up with those of the central leader trees with horizontal branch training by the last measurement cycle, the results suggest that the central leader trees with horizontal branch training may have an initial advantage in terms of growth rate but that further investigation is needed to clarify its impact on longer-term tree vigour.

Regarding flowering and fruiting, in contrast to an apparent stimulation of early growth, central leader trees with horizontally trained branches appeared to have a disadvantage. Central leader-trained trees with angled branches and free-standing trees had a slightly higher proportion of trees with flowers or fruit by November 2023. These results suggest that while initial reproductive development may vary, each training system eventually supports the initiation of fruiting by a similar time point.

In conclusion, the results from the Laudham Park site indicate that tree training trellising can provide advantages in early jackfruit tree growth. Trees trained to a central leader with horizontally trained branches showed superior early height and trunk cross-sectional area, suggesting a stronger structural foundation. However, over time, other training systems, including those with angled branches and free-standing trees, demonstrated better or comparable early fruiting potential.

General conclusions for the Queensland sites

Overall, the trials conducted across the Queensland sites—South Johnstone, Bellenden Ker, Mutchilba, and Townsville—provide valuable insights into the early growth dynamics of jackfruit trees under various training systems, propagation methods, and planting densities. Each site offered unique characteristics and findings that contribute to an understanding of jackfruit cultivation in Queensland. Due to variability in planting times and types of planting material, it is not possible to conduct a thorough comparison between the sites. Instead, our general conclusions draw on key similarities and contrasts noted.

Trellising

The Bellenden Ker, Mutchilba, and Townsville sites contained both trellised and untrellised trees, however, strong conclusions cannot be drawn about whether trellising improves vegetative vigour (or restricts it?) of young jackfruit trees since the results are variable among the sites. For some sites (Townsville), trellising appeared to benefit growth, while for others (Mutchilba), it did not have a clear effect. At Bellenden Ker, the influence of trellising versus free-standing trees in benefiting growth was largely determined by tree propagation type. Overall, branch training strategy also had a significant effect on determining the efficiency of trellising for benefiting tree growth. Therefore, for the purpose of this report, we cannot elucidate if trellising of jackfruit trees is likely to be beneficial for early or longer-term tree growth and fruiting.

Branch Training Techniques

There are some indications that angled branch training consistently induces vigorous growth, as tree height and trunk cross-sectional area development performed well for trees trained with angled branches at all four sites. The results suggest that angled branch training is likely an effective system to promote early growth of jackfruit trees. Horizontal branch training induced comparable good results to angled training in terms of tree growth, but with slightly less consistency across sites. For instance, it produced similar results in terms of tree height and trunk cross-sectional area development compared to angled training for the South Johnstone and Townsville sites, but not consistently so in Mutchilba and Bellenden Ker. For the latter, propagation material differences appear to influence the success of horizontal branch training in promoting vigorous growth. Candelabra training was only assessed in South Johnstone and performed poorly, so it should best not be considered if early vigorous growth is desired.

Although conclusions regarding tree training effects on reproductive development cannot be made from the limited data collected, the results suggest that angled branch training induces promising effects for early flower and fruit establishment. However, by the end of the observation period, fruiting potential was generally comparable across different systems.

Propagation Material

The diversification in use of grafts, cuttings, and/or seedlings across the sites provides some insights. However, irregularities in their application, particularly concerning planting densities and timing, make it difficult to draw strong conclusions about their effects on early tree development. Nevertheless, at South Johnstone and Bellenden Ker, it appears that seedlings and grafted trees exhibit more vigorous early growth than cuttings, but the growth of cuttings may eventually catch up, particularly to grafted trees. Furthermore, grafted trees appear to induce flowering and fruiting slightly earlier than trees propagated as cuttings, however these results are likely driven by disparity in planting timing. Further work is needed to assess if propagation material has a long-term effect on the fruiting pattern of jackfruit trees.

Planting Density

We can conclude that ultra-high-density planting slowed early growth compared to high-density plantings, but minor spacing variations within ultra-high density had limited impact.

Take Home Message

Overall, these findings provide a foundation for optimising jackfruit orchard management practices, emphasising the importance of selecting appropriate branch training systems, propagation methods, and planting densities to achieve desired growth outcomes. Further long-term studies are needed to fully understand the impacts on tree vigour and fruit production.

Chapter 2: Western Australian trial sites

Introduction

In Western Australia, tropical and subtropical horticulture is predominantly located within two northern districts – the Ord in the semi-arid tropics of the East Kimberley and Carnarvon in the arid subtropics of the Gascoyne. Both districts are geographically isolated in the northwest of the state and experience cyclones. The WA Department of Primary Industries and Regional Development hosts stations for agricultural research at the Frank Wise site, roughly 20 km north of Kununurra in the Ord district, and at the Carnarvon Research Station, 10 km to the east of Carnarvon.

Perennial crop systems endure annual weather cycles and extreme weather events, such as cyclones. Next-generation systems incorporate known climate data into the design and management of orchards to build resilience. Temperatures and rainfall of the Carnarvon and Kununurra Research Stations were compared with BoM data from the Katherine Research Station in Northern Territory and the South Johnstone Research Facility, Queensland, from 1994 to 2024. The aim was to better understand the variations that occur throughout the tropical fruit growing regions of northern Australia, from the wet tropics to the arid coast. It is worth noting that Kununurra mean maximum temperatures were consistently the highest of the sites (Figure 60). Carnarvon mean minimum temperatures were the lowest of the compared sites from June through December. It is unknown whether the extremes in temperatures experienced within the WA trials are detrimental to jackfruit establishment and production. Additionally, rainfall and the associated cloud cover and humidity will likely influence plant growth and development in different ways across all four sites (Figure 61). South Johnstone has an average of 15 times more rainfall than Carnarvon.

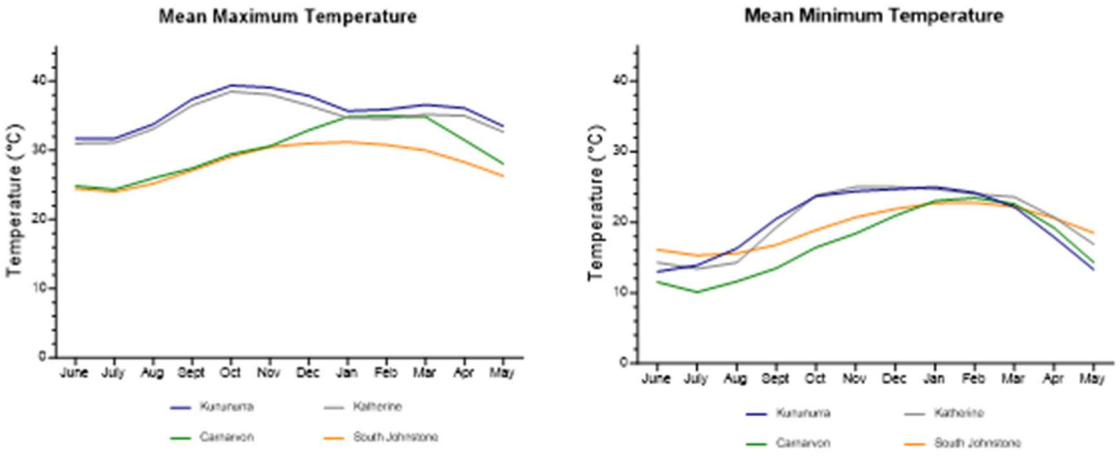


Figure 60. A comparison of monthly mean maximum temperatures and mean minimum temperatures from 1994 to 2024.

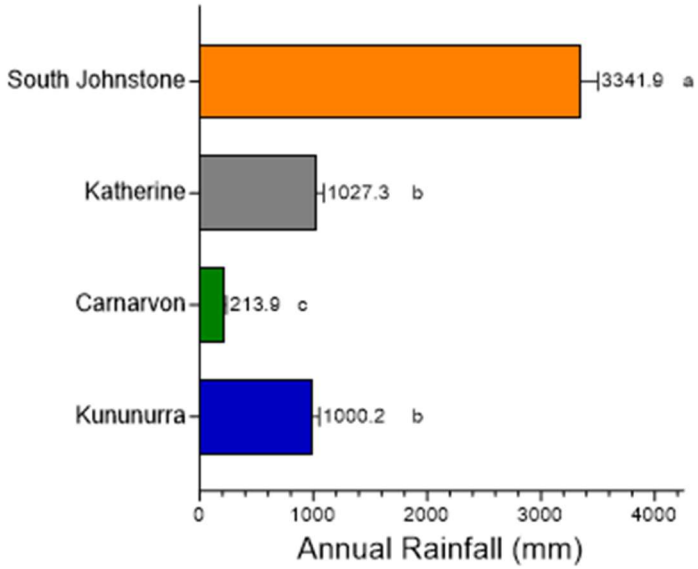


Figure 61. Mean annual rainfall for South Johnstone, Katherine, Carnarvon, and Kununurra from 1994 to 2024. Letters correspond to statistical significance, which was accepted as $p<0.001$.

Site Locations

Carnarvon Research Station (24°51'18"S 113°43'43"E)

Carnarvon Jackfruit Trellis Trial

The Carnarvon Jackfruit Trellis Trial was planted in November 2021 on a silty clay loam. The trial consists of 100 trees grown from seeds of the variety, Rajang, which were germinated and grown in 150 mm pots in the research station nursery. The trial has an NNW-SSE orientation with ten mounds (300 mm high x 1500 mmm across) and 2500 mm interrow. Ten trees are planted along the mounds with a spacing of 3 m between the trees and 4 m between the rows. The wooden trellis structure spans six of the ten mounds, with the first wire at 700 mm and additional wires every 500 mm. The four remaining mounds are not trellised. Canopy training across the trial are outlined as multi-leader on trellis, palmette on trellis, multi-leader freestanding, and single-leader freestanding (Figure 62 and Appendix A). There are six replicates of five trees (n = 30) across the trellised training methods, and four replicates of five trees (n=20) of the freestanding training methods. Poor establishment and disease over the trial period has led to significant losses as well as high variability in size between trees within the trial.



Figure 62. Aerial drone image of Carnarvon Rajang Trellis Trial taken in August 2024. Note the missing trees and variable canopy size. The row of mature trees to the right of the image are mangoes.

Carnarvon Seedling Variety Trial

The Variety Trial was planted in November 2021 in the adjacent block on silty clay loam. It is a single-tree randomised block design with 54 trees across nine ENE-WSW oriented rows. Rows are mounded (300 mm high x 2000 mm across)

with 4 m interrow spacing, for a tree spacing of 5.5 m x 6 m. Seedlings grown from six accessions of jackfruit were planted across the block. Seeds from two of the accessions are of the known varieties Rajang and Black Gold. The remaining four accessions are unknown and have been grown from seeds of fruit donated by three local growers and one purchased from the Perth market (Figure 63 and Appendix B). Roughly half the block failed to establish, likely due to a combination of planting 90-day old trees and poor disease management. Dead trees were replanted in October 2023 from remaining plant material in the research station nursery.

Carnarvon Agroecosystem Pilot

A two-row pilot demonstration was implemented in November 2023. Ground preparation involved a pre-planting ground treatment of metalaxyl for Phytophthora and Pythium. Two rows of eight papaya plants (3 m spacing) were planted and established over the hot season. Once the papayas reached 1600 mm in height by March 2024, 12-month-old CP47 seedlings were planted between the papaya (1500 mm from papaya plants). Additionally, parsley and basil were sown across the mounds (Figure 63, two rows on the right). The plants were irrigated and provided with nutrients to assess the viability of a future trial using a multi-storey canopy approach.



Figure 63. Drone image of Carnarvon Variety Trial and Agroecosystem Pilot Trial (furthest two rows on right) in August 2024. Note the missing trees and variable canopy size.

Kununurra/Frank Wise Research Station (15°38'39"S 128°41'41"E)

Kununurra Trellis Trial

The Kununurra Jackfruit Trellis Trial was planted in February 2022, using 6-month-old seedlings of the Galaxy variety. The ‘levee block’ was chosen as the planting site as it contains a well-draining sandy loam which was deemed more suitable for jackfruit when compared with the well-known Ord District black soils. Border trees of the Rajang variety were planted around the outside of the trial. The trial consists of 8 rows of 8 trees, with a tree spacing of 4 m and row spacing of 4.5 m (Figure 64 and Appendix C). Steel pole trellising has been erected on 4 out of the 8 rows, with the first wire at 800mm height and additional wires every 900mm. The trees chosen for monitoring growth are trees 2 and 5 in each row (freestanding n= 6, trellis n=10) this is done to ensure an appropriate buffer on either side of the trees being monitored (Appendix D).



Figure 64. Aerial drone image of Kununurra Galaxy Trellis Trial, taken in June 2024. Note the single row of grafted trees on the far-left side of the trial.

Rajang Cutting Trial

Thirty-six cuttings from a single mother tree of the Rajang variety were prepared in South Johnstone, QLD and brought back to Kununurra in July 2022. The cuttings were planted on the 'levee block' near the Trellising trial in July 2022. Height is the only factor being recorded on a bimonthly basis, since January 2023. The purpose of these cuttings is to provide insight into how cuttings from the Rajang variety of jackfruit perform in local conditions.

Kununurra and Carnarvon weather and associated management practices

Weather data were collected across both WA sites for the duration of the project through the WA DPIRD Carnarvon 1 Weather Station and WA DPIRD Kununurra Weather Station. The data were compared to inform the research and aid in management decision making.

Rainfall

Rainfall patterns in Kununurra follow a monsoonal pattern with a distinct wet season from December to April (Figure 65). Carnarvon rainfall occurs sporadically from February through August, generally with storm and cyclone events. Both sites experienced lower than usual rainfall in 2023 and high than usual rainfall in 2024. It is speculated that the increased rainfall in Carnarvon has facilitated the spread of the pathogenic oomycete, *Phytophthora palmivora*.

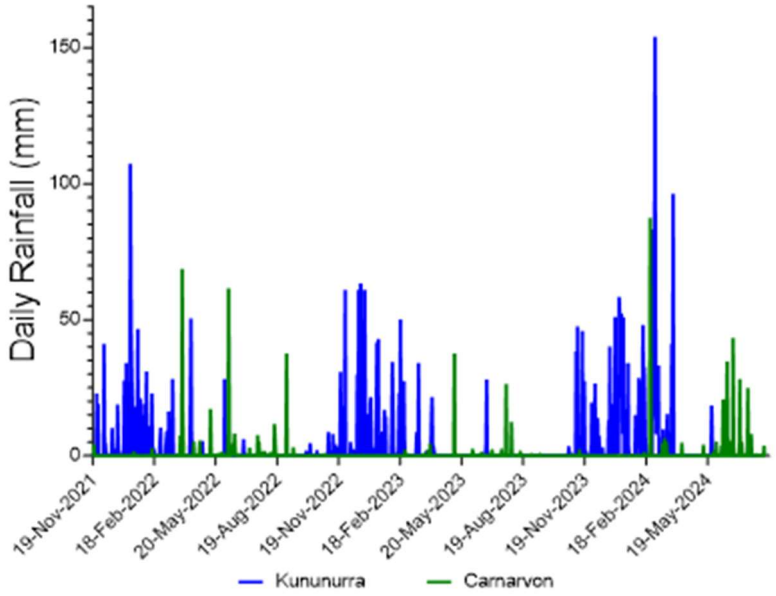


Figure 65. Daily rainfall throughout the establishment of the jackfruit orchards.

Solar Exposure

In addition to the annual rainfall cycles, both Carnarvon and Kununurra experience cyclic patterns in solar exposure and evapotranspiration. Solar exposure in Carnarvon is extreme, with daily values reaching over 35 MJ between November and January (Figure 66, left). Kununurra also experiences high exposure (up to 31 MJ), but it is often moderated by cloud cover during the wet season. In Carnarvon, young jackfruit trees were sprayed with a kaolin-based crop protectant (Surround WP) to protect the leaves from sunburn during the peak exposure period. This is common commercial practice and is necessary until trees develop a larger canopy that can shade the trunk and main leaders.

Jackfruit are phototropic and were found to direct their growth toward the angle of the sun. Jackfruit planted along east-west running rows in both Kununurra and Carnarvon often develop an imbalanced canopy with more vegetative growth on the northern side of the canopy, to maximise solar exposure (Figure 67). Commercial plantings should consider the phototropic tendencies of jackfruit when designing orchards. Additional research should be performed to identify the optimal row orientation in various growing location to maximise performance and productivity.

Evapotranspiration

In Carnarvon and Kununurra, the combination of extreme solar exposure, extreme temperatures, and extreme vapour pressure deficit, do impact plant evapotranspiration. Reference evapotranspiration was estimated using the FAO Penman-Monteith equation calculator built into the WA DPIRD weather stations with a crop coefficient for crops roughly 3 m tall. Each year during the trial period, Carnarvon frequently exceeded 10 mm of estimated evapotranspiration during the hot, dry months, December through March (Figure 66, right). Irrigation practices were altered during this period to increase soil moisture by pulsing drip irrigation for five minutes every 90 minutes. Pulsing drip or sprinklers to accommodate extreme evapotranspiration are common practice within the Carnarvon Horticultural District.

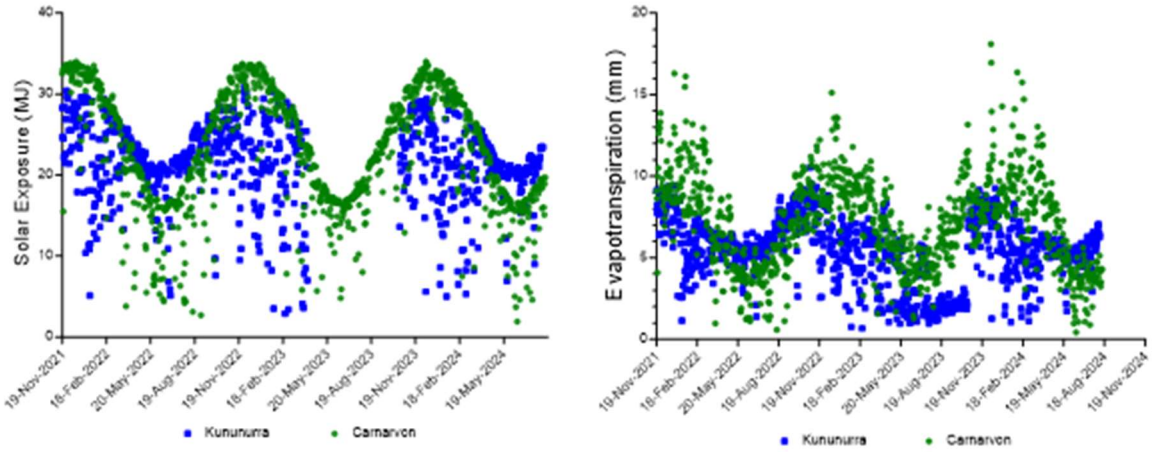


Figure 66. Solar exposure and estimated evapotranspiration throughout the project lifespan.



Figure 67. Carnarvon Variety trees demonstrating phototropism. E-W oriented rows have encouraged trees to produce more vegetation on the northern side of the canopy.

Wind direction and windspeed are factors that impact orchard management at the WA sites. Windspeeds tend to be higher in Carnarvon and orchard row orientation is often angled to direct the flow of prevailing winds (Figure 68). Both sites installed tree guards, made from rabbit wire and shade cloth, to protect young trees from strong winds during the establishment phase (Figure 69). Guards were removed when the trees outgrew them.

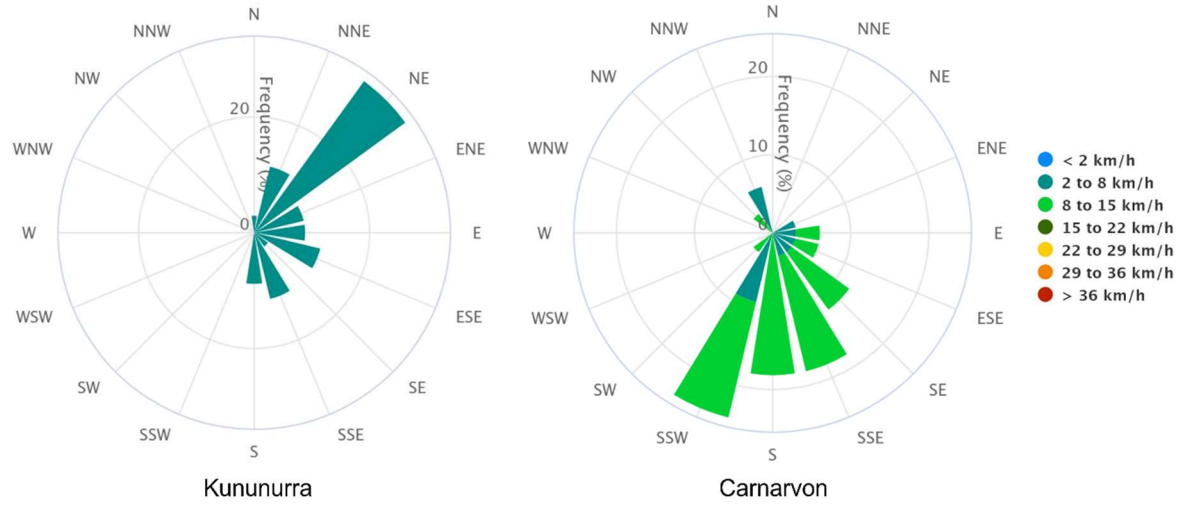


Figure 68. Wind rose data from Kununurra and Carnarvon, 2021 to 2024.



Figure 69. Wind guards surrounding establishing trees in 2022.

The trellis system was installed as a support system, especially during high winds and cyclone events. During the project span, only one cyclone event occurred in the Ord and Carnarvon Districts. Ex-Tropical Cyclone Lincoln traversed Queensland and Northern Territory, before downgrading to a tropical low and bringing roughly 40 mm of rainfall to Kununurra. It continued across the Kimberley and regained momentum in the Indian Ocean, as it intensified to a Category 3 off the Pilbara and Gascoyne Coast. However, it was downgraded again to a tropical low shortly before reaching land, approximately 50 km north of Carnarvon. Windspeeds reached 75 kph but did not damage the trial. The only detrimental impact was due to heavy rainfall of 80 mm over four hours. The rainfall eroded mulch off the mounds and subsequent waterlogging spread Phytophthora throughout the trial blocks. Overall, Ex-Tropical Cyclone Lincoln demonstrated the highly variable tracking of cyclones and their ability to impact vast areas across northern Australia.

Carnarvon Trial Results

Carnarvon Variety Trial

The initial phase of planting and orchard establishment was managed with difficulties at the Carnarvon site. As a result of frequent staff turnover, three-month-old jackfruit seedlings, roughly 150 mm in height, were planted in the field at the beginning of the hot season. Tree guards were placed around them and removed after four months. Roughly 30% of the trees were lost within this timeframe. These early failures indicate that planting should occur outside of the hot season, plant material should be more mature, and appropriately hardened off prior to planting.

The remaining trees were recovered by replacing tree guards and improving nutrition and irrigation management plans. By December 2022, trees had improved to a point where measurements could be collected. Tree height and trunk diameter data were collected quarterly to track vegetative growth from December 2022 to March 2024 (Figure 70).

Two local accessions, coded as GUG and MOR (Appendix B), have shown the most promise in terms of establishment, growth rate, and fruit set. Both accessions have had the fewest losses; only one tree out of nine. They also displayed the most vigour in terms of height and trunk diameter, despite the persistence of significant disease pressure within the block. A disease complex with Phytophthora palmivora and Pythium species were detected in 2023, resulting in the loss of multiple Black Gold, Rajang, SUT, and WAG trees. To date, no GUG and MOR trees have been lost to the disease. Instead, they have displayed rapid growth and distinctive growth habits. GUG trees are taller with a more open canopy. MOR are shorter with a dense canopy, requiring more frequent pruning.

GUG and MOR are the only accessions in the Variety Trial to produce fruit. Once fruit set occurred in November 2023, fruit was thinned to two per tree to avoid excessive drain on carbohydrates from growth as well as to avoid possible biennial bearing. Unfortunately, all fruit were removed on 22 February, 2024 during orchard preparation for ex-Tropical Cyclone Lincoln, under the advice of project leads in South Johnstone. QLD. Therefore, fruit quality evaluation was not performed.

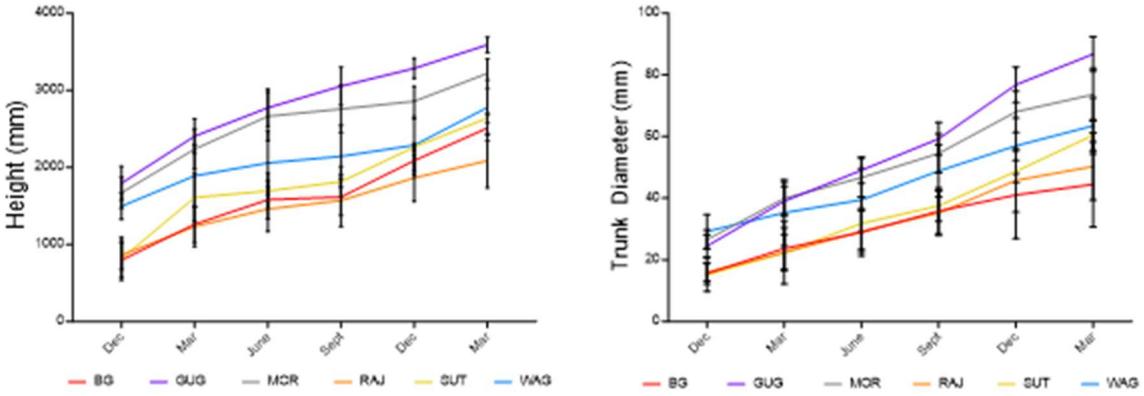


Figure 70. Carnarvon Variety Trial height and trunk diameter over time.

Carnarvon Trellis Trial

Much like the Variety Trial, the initial establishment phase of the Trellis Trial was managed with difficulties. This led to losses of roughly 10% of the trees within the first four months. The damage was exacerbated by a severe pruning of young trees at the beginning of the cold season, roughly five months post-planting. The pruning event led to the loss of an additional 20% of the trial. These actions demonstrated that the first pruning should be light, it should not occur during the first year after planting, until trees have established a solid root system, and should not occur during the cold season.

Due to the severe early pruning, tree measurements were not an indicator of growth and development until 2023. Instead, a simple scoring method was developed based on tree size (Figure 71). The score identified the rough growth rate of trees over time. The downturn in growth rate on Single Leader training method is due to the rapid spread of *Phytophthora palmivora* through the trial block following the ex-Lincoln rainfall and waterlogging event. Despite soil treatments with metalaxyl and foliar sprays of phosphorous acid, many Single Leader trees could not be recovered.

It should be noted that all Rajang trees exhibited mild chlorosis during the colder months (June through August). Additionally, once trees were established, the multi-leader and palmette training methods on trellis required pruning every two months to maintain the correct tree shape along the trellis. All freestanding trees required pruning every four months. The combination of installation costs and the additional labour required to maintain the trellised trees could become unviable for commercial adoption in Carnarvon. As of August 2024, there is an 18-month waitlist for the construction of a trellis structure in the Carnarvon Horticultural District due to regional skilled labour shortages. Local logistical constraints of infrastructure installation and maintenance should be considered by growers prior to adoption across the north of Australia.

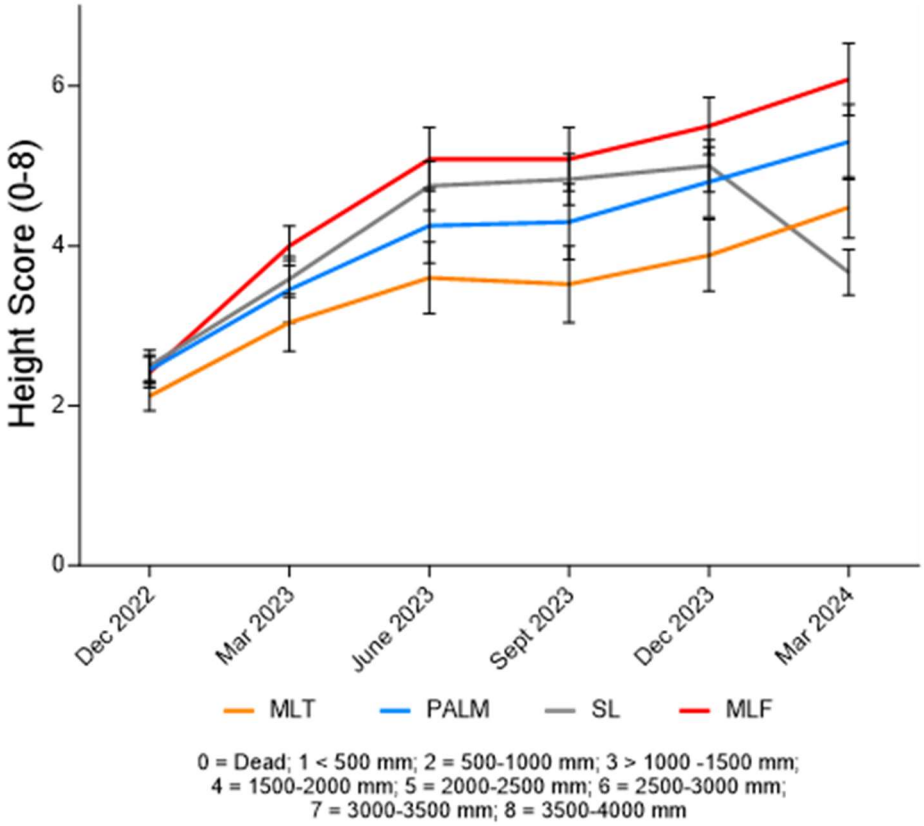


Figure 71. Carnarvon Trellis Trial tree scoring over time. Note the decline in growth of Single Leader trained trees during Quarter 3 of 2023-2024.

All training methods lagged in growth score over the cold season (June through September 2023). Like most fruit trees, the cold season nightly minimum temperatures would be impacting jackfruit growth and development. Further data collection on temperature effects on tree growth and development and the possible identification of growth thresholds was deemed important. Triplicate temperature sensors were installed to measure air temperature (Campbell Scientific HygroVue 10), irrigated soil temperature and moisture at 300 mm depth in the rootzone (Campbell Scientific CS-650) , and unirrigated soil temperature and moisture at 300 mm depth in the interrow (Campbell Scientific CS-650). Six infrared radiometers (Apogee SI-431-SS) were installed to measure canopy temperature and paired with six trunk dendrometers (METER Group DE-1T) on multileader trained trees.

Diurnal temperature swings are high in Carnarvon and may influence heat and cold stress recovery and could be helpful in determining timing and volume of irrigation. To illustrate this concept, the mean temperatures were calculated across all replicates and daily mean minimum and mean maximum temperatures were analysed. As expected, 15 to 20-degree diurnal air temperature swings were common across the measurement period (Figure 72). The diurnal swing in canopy temperatures was slightly greater than air temperatures, likely due to leaf surface temperatures increasing during solar exposure.

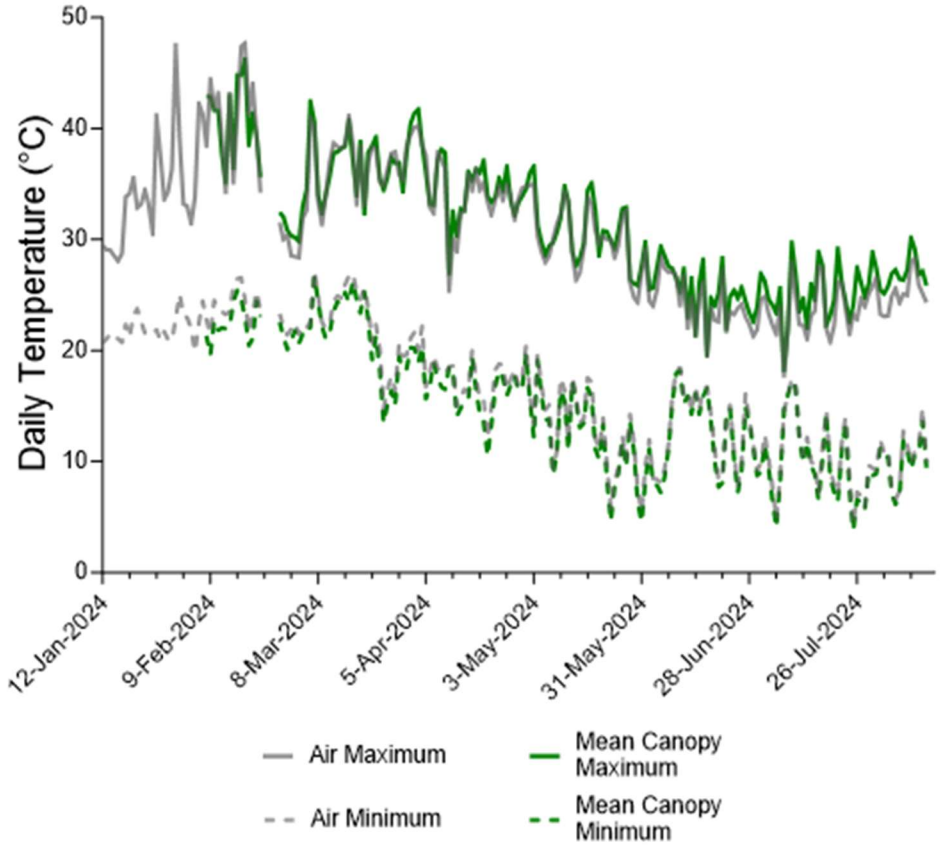


Figure 72. Mean diurnal temperature differences in air and canopy temperature in trellised Rajang orchard. Note the gap in data collection between 23 February and 27 February when monitoring equipment was removed from the field during cyclone preparation.

In contrast to the canopy temperatures, irrigated soil temperatures were relatively stable, with mean minimum and maximum rarely exceeding 2 ºC (Figure 73). Unirrigated interrow soils experienced much higher temperatures, reaching 40 ºC during the hot season. These temperatures increase at the soil surface and were measured with an infrared thermometer at temperatures exceeding 55 ºC during heatwaves. This demonstration highlights the necessity for controlling interrow soil temperatures within Carnarvon orchards. It may be possible to reduce unirrigated soil temperatures and soil surface temperatures via cultivation of an interrow cover crop. Furthermore, the reduction of radiant heat off the soil surface may reduce canopy temperatures. Care should be taken in the identification of the most appropriate interrow ground cover depending on the irrigation management. Survival could become difficult during the hot season if not irrigated.

In October 2023, a dual system of Netafim UniRam CNL orchard dripline was installed across the mounds, roughly 300 mm out on both sides of the trunk. This allowed for better management of soil temperature and moisture by 5-minute pulsing of the drip irrigation, at 90-minute intervals, to keep the soils moist during heatwaves.

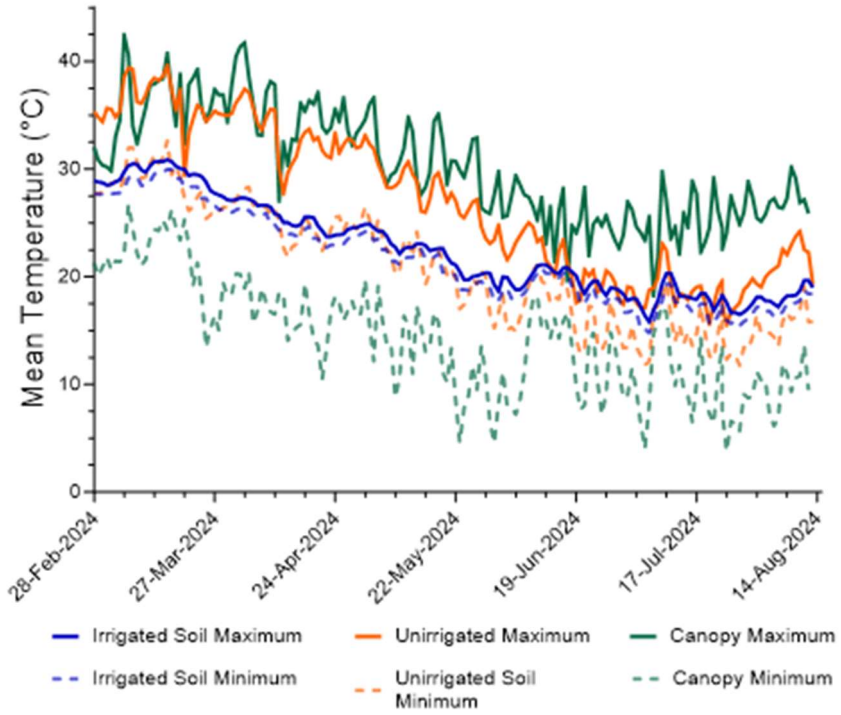


Figure 73. Comparison of mean minimum and maximum temperatures of the canopy, irrigated, and unirrigated soils at 300 mm depth.

Trunk dendrometers captured the trunk evolution over time, as well as daily growth rate and the maximum daily shrinkage. These metrics can be used to better understand plant growth, response to stress over time and utilised to better manage irrigation volume and timing. The mean daily maximum and minimum readings show a positive trend with mean trunk expansion of over 5 mm from February 2024 to August 2024 (Figure 74). There have been negative turns of trend, however the trend across the cold season has been stable and may indicate that the colder weather has not been detrimental to trunk expansion.

Trunk maximum daily shrinkage is associated with transpiration and may be impacted by vapour pressure deficit. Figure 75 illustrates the relationship between growth rate and vapour pressure deficit. Vapour pressure deficit reduces seasonally from mid-May through August. Trunk shrinkage appears to follow this trend. Further data collection over multiple seasons and in-depth analyses are necessary to elucidate the trends between jackfruit tree growth and environmental pressure. The data will also help in establishing more functional irrigation protocols for growers.

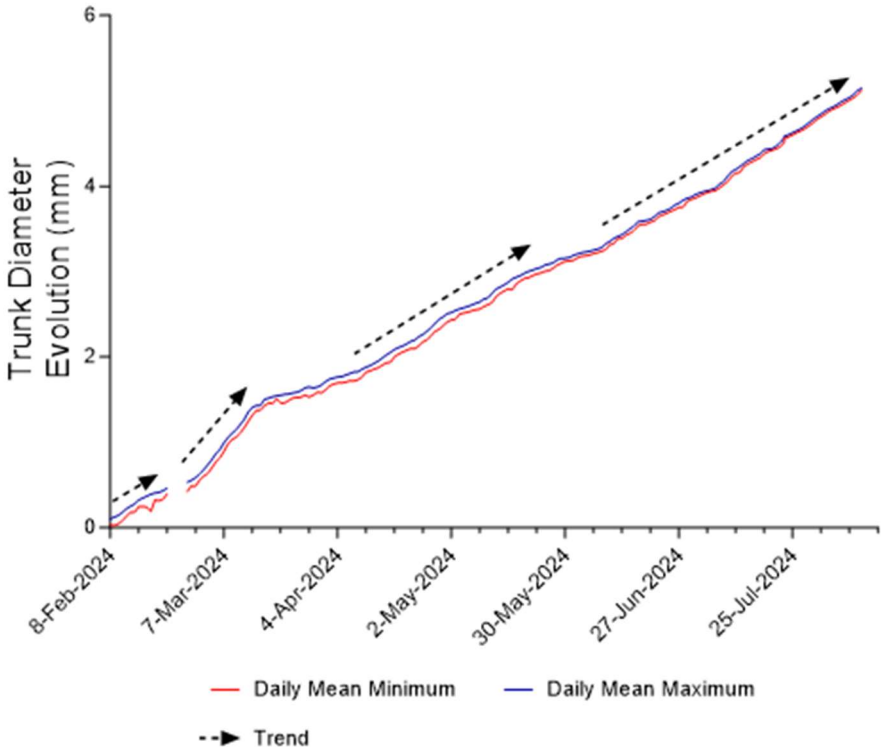


Figure 74. Trellised Rajang trunk diameter evolution over time. Note the gap in data in February corresponds with the removal of field equipment in preparation for ex-Tropical Cyclone Lincoln.

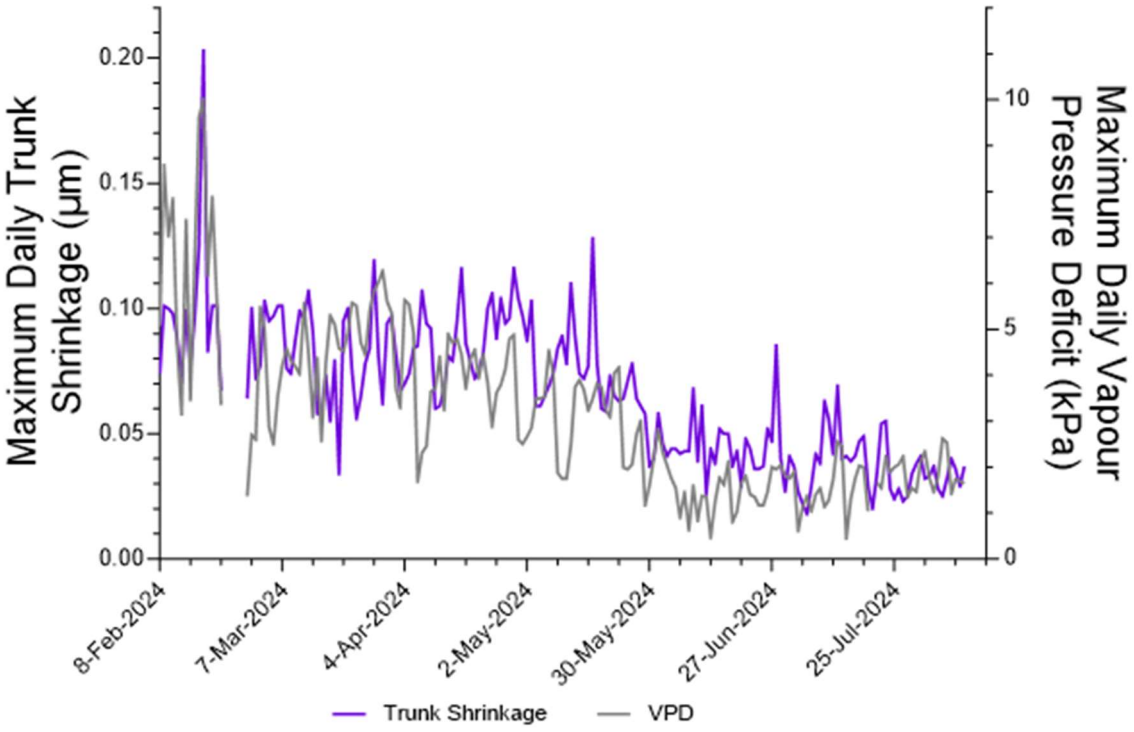


Figure 75. Comparison of maximum daily trunk shrinkage with vapour pressure deficit. Note the gap in data in February corresponds with the removal of field equipment in preparation for ex-Tropical Cyclone Lincoln.

Carnarvon Agroecosystem Pilot

The climatic data, weather data, and orchard environmental data suggest that abiotic stress in Carnarvon is high and may have contributed to poor orchard establishment. It was hypothesized that altering orchard mesoclimate and canopy microclimate through development of an agroecosystem may improve establishment under Carnarvon conditions. As this project sought to demonstrate next-generation orchard production systems, a simple pilot trial was established to exhibit a possible alternative for growers.

Papaya were planted to provide shading for young jackfruit trees, whilst possibly offering an earlier return-on-investment (Figure 76). 12-month-old CP47 jackfruit seedlings were planted between the papaya plants with the idea to provide shading from the harsh Carnarvon solar exposure. Unfortunately, the rows were created with an ENE-WSW orientation (parallel to South River Road) instead of due E-W. This prevented the papaya from providing optimal shade. Growers should consider their row orientation and shade angles prior to planting. It may be beneficial to plant jackfruit at uneven spacing between the papaya, distanced between the papaya plants but closer to the trunks to increase the benefit from the natural shading. Finally, parsley and basil were direct seeded as ground cover to shade the soil and reduce the effects of radiant heat in the orchard. All crops have successfully grown within the pilot trial. Overall, this pilot demonstrates the need for future research into intercropping systems, canopy microclimate, yield, long-term orchard production, and what a next-generation production system looks like under varying environments.



Figure 76. Agroecosystem Pilot with papaya, jackfruit, basil, and parsley. Red circles highlight young jackfruit trees. Blue lines have been drawn underneath the basil and parsley ground cover.

Carnarvon Nursery Material

Due to the complications with orchard establishment in 2021 and 2022, it was decided that a small seedling trial in the research station nursery should be implemented. The aim of this trial was to track germination and growth rates, following strict practices to determine if seedlings could be adequately raised under Carnarvon environmental conditions. In November 2022, 128 Rajang seeds were posted from South Johnstone, QLD. They arrived within five days and were treated with a fludioxonil fungicide dip (Scholar®; 6 mL/10 L), prior to being sown into trays of 90% coir and 10% perlite. Care was taken to orient seeds so the radicle would emerge downward. Germination of the first seeds occurred within 10 days of sowing. Within 24 days of sowing, 126 seeds had germinated. Once seedlings reached 300 - 400 mm in height, they were gently transplanted into 2.8 L plastic grapevine bags with a blend of 65% cocopeat, 20% composted mulch, 10% sand, and 5% perlite. Transplanted seedlings were top-dressed with coir.

In March 2022, seeds from fruit of C1, C2, CP47, and T6-2 cultivars were posted from South Johnstone, QLD. They arrived within five days and were treated with fungicide and immediately sown into trays of coir and perlite as previously described (Figure 77). Germination of the first seeds occurred within 14 days of sowing and cotyledon emergence had occurred on all viable seeds within 22 days of sowing. Again, once seedlings reached 300 – 400 mm in height, they were transferred to plastic bags following the previously state method (Figure 78).

Germination rates were consistently high across all varieties (Table 1). This suggests that the techniques employed during the germination exercise were acceptable and growing jackfruit from seed may be an affordable option for growers when procuring clonal material is difficult.



Figure 77. Germination of jackfruit seeds in coir and perlite media.



Figure 78. Jackfruit seedlings at 26 days after sowing.

Table 79. Jackfruit seed germination rates.

Variety	Number of seeds received	Germination (%)	Seedling survival after 12 months (%)
C1	30	100.0	100.0
C2	18	94.4	88.2
CP47	40	97.5	97.4
T6-2	30	100.0	100.0
Rajang	128	97.6	95.2

Seedling height was measured every six weeks once seedlings reached roughly 250 mm in height. Rajang displayed the lowest growth rate, while C2 and CP47 had the highest (Figure 79). Early vigour may be beneficial under WA conditions as young plants will need sufficient leaf area to cope with solar exposure. For this reason, C2 and CP47 were identified as varieties for future investigation. It was speculated that temperature may play a role in seedling vigour, as the Rajang growth rate was slow across the cold season (May through August). The highest growth rates in all varieties were achieved when mean nursery daily maximums exceeded 32 ºC. Further work is necessary to unravel the relationship between seedling vigour, temperature, and variety. Establishing correct seasonal windows for germination and planting will be necessary for future grower adoption of seedling plant material.

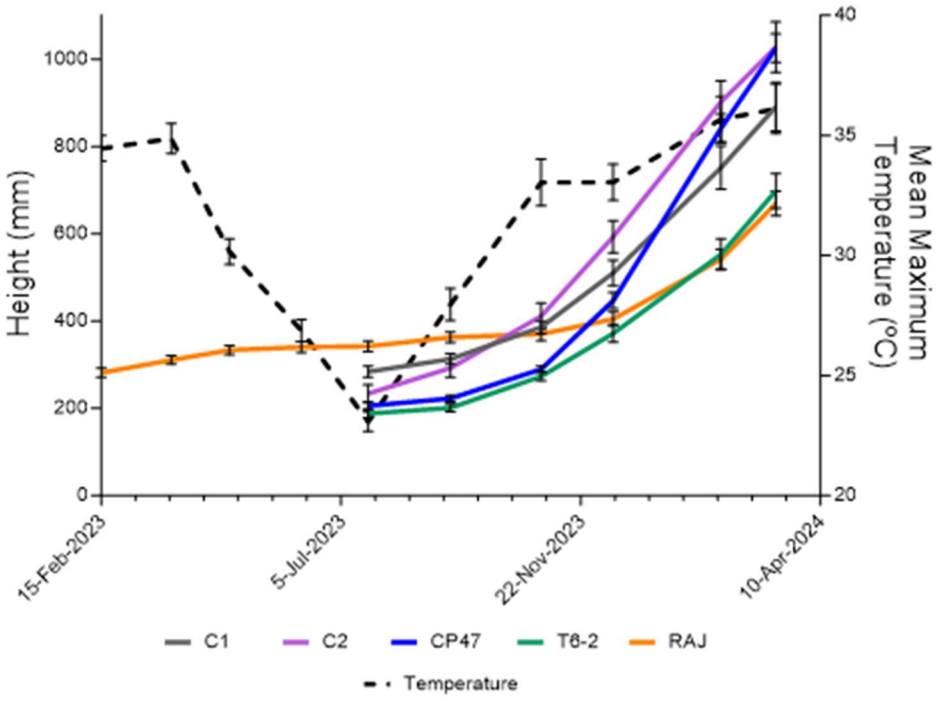


Figure 80. Nursery seedling growth over time with the mean maximum daily temperature plotted for each sampling period.

Kununurra

Kununurra Trellis Trial

The Kununurra Trellis Trial consists of 48 seedlings of Galaxy trees planted along eight rows. East, west, and south single guard rows contain Rajang trees, while the northern guard row is a mix of grafted trees, including CP47 as a scion. There were only two trees deaths which appeared in areas that were waterlogged for multiple weeks during the wet season. In 2023 and 2024, chlorosis was present during the cool dry season but vanished as temperatures warmed throughout August. Similarly to Carnarvon, this seasonal chlorosis should be monitored to determine if specific fertilisation should be applied, especially when trees will be older and in production. The trees had a rather uniform growth habit, especially when compared to Carnarvon. Trees gained roughly 2000 mm in height over the course of the trial (Figure 80) with a reduction in freestanding height in October 2023 due to pruning.

Two-way ANOVA with Tukey's multiple comparisons test of tree height found that palmette was significantly shorter than freestanding trees ($p = 0.003$). Trunk diameter was also significantly different between each training method. Overall, freestanding trees have the most vigour. This may indicate that the reduction of canopy to suit training methods on trellis may have a detrimental effect on tree growth under Kununurra environmental conditions. It is unclear whether there is a benefit to planting jackfruit on a trellis system in Kununurra.

The first flowering of Galaxy and Rajang trees occurred in June 2024 and continued through August 2024. While the early flowers appeared on the terminal ends of branches, later flowers in July and August were found on the trunks and main leaders. The early terminal flowers did not set fruit. Flowers on trunks and main leaders have set fruit.

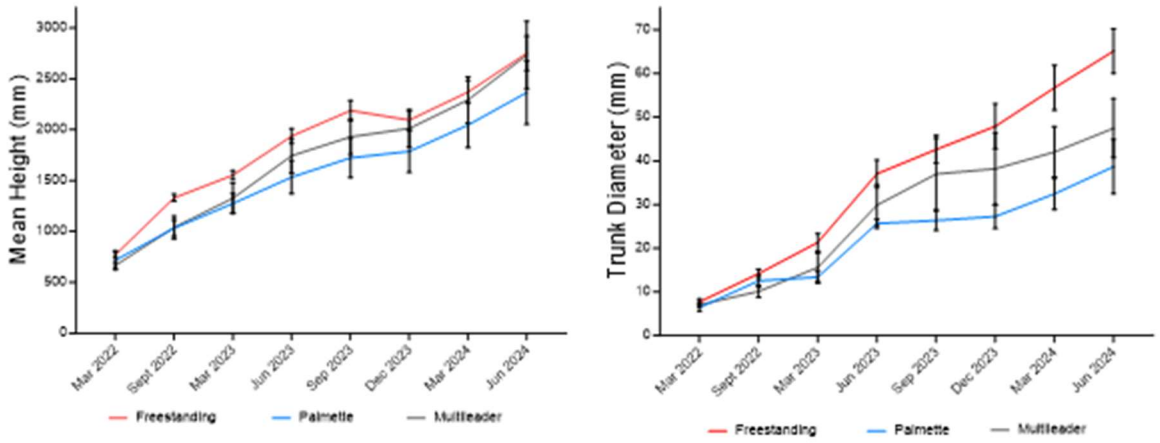


Figure 81. Kununurra Trellis Trial Galaxy tree height and trunk diameter over time.

Kununurra Cutting Trial

The Rajang cuttings were collected and rooted in South Johnstone, Queensland in July 2022 and transported through Western Australia Biosecurity Quarantine. Cuttings were transplanted into the field in Kununurra and protected with tree guards. Establishment was slow, with a mean height increase of 344 mm over a 20-month window (Figure 81). It was speculated that cuttings should have been transferred to the research station nursery to acclimate to Kununurra conditions before transplanting into the field.

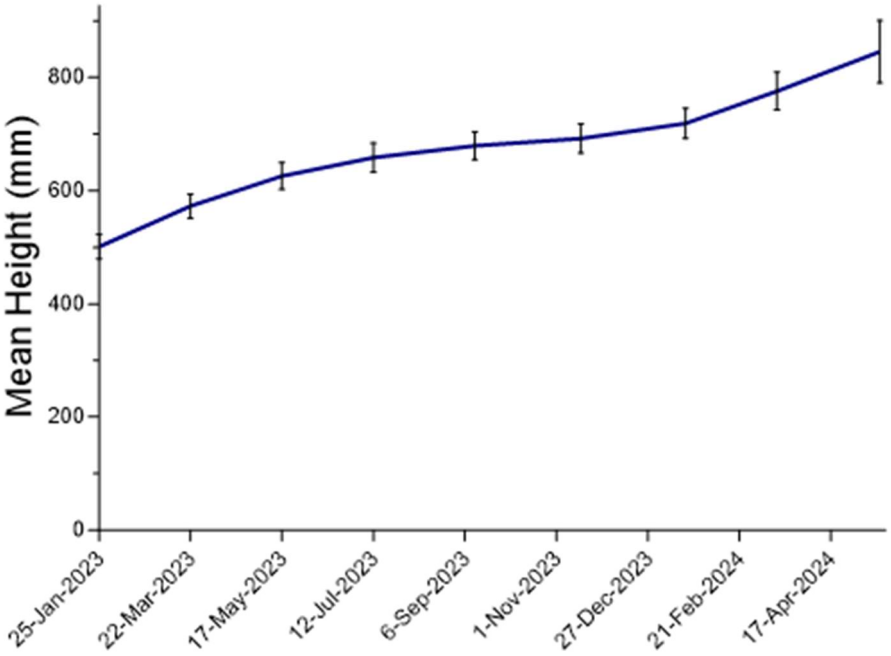


Figure 82. Kununurra Cutting Trial tree height over time.

Grafted Trees

A guard row of grafted trees was planted as the northern-most row in the Trellis Trial. While there is no replication and evidence is simply observational, the growth habit of grafted trees should be more suitable than seedlings. The grafted trees have a shorter and rounder stature which provides ample shading of the trunks and buds, which are located along the collars of trunks and main leaders (Figure 82). The seedling trees have exposed trunks over 1000 mm in height which may be prone to sunburn when solar exposure is high. In addition, seedlings have notoriously much higher variability within a population than grafted trees.



Figure 83. (Left) Guard row of grafted trees with short trunks and bushy canopy. (Right) Galaxy seedling trees on trellis with long, exposed trunks.

Summary

The diversification of tropical crop production is essential for developing a sustainable agriculture sector across northern Australia. This project sought to demonstrate next-generation resilient orchard production systems, based on local environment and local logistics, which vary across the north of Australia. This was accomplished through the use of high-density and trellised planting systems, experimentation in plant propagation methods and orchard establishment techniques, and the identification of diverse plant material that is suitable under different climates across the north.

In WA, the sites at Kununurra and Carnarvon have demonstrated the need for adaptability of orchard establishment and management practices to suit each environment and farm. The subtropical, arid Carnarvon site pushes the environmental boundaries for tropical fruit cultivation with extreme heat, sunburn, low rainfall, and cool winter night temperatures. To cope with these pressures, the trellis structure was designed from 200 mm wooden posts and drip irrigation is essential to maintain trees in an environment with an average of 213 mm of rainfall per year. The intense solar exposure requires the application of kaolin-based foliar crop protectant to prevent sunburn on leaves and branches. In tropical Kununurra, a steel pole trellis structure was erected to prevent termite damage and sprinkler irrigation is used for roughly eight months of the year. Waterlogging became an issue during the 2023 wet season following multiple heavy rainfall events. These examples highlight the necessity for flexible management practices.

The trellis system trials yielded mixed results at both WA locations. At this early stage in orchard establishment, there are no clear benefits to utilising a trellis system under WA conditions, apart from cyclone protection, which was never tested due to lack of cyclonic events. In Kununurra, trellised trees have less vigour and have taken longer to establish. The phototropic growth habit of the trees at both sites requires frequent labour to prune and train the trees along the trellis. The additional labour required to maintain the jackfruit trees on a trellis may be cost prohibitive. However, once the trees are fully established and trained, a trellis system could facilitate mechanical pruning as well the readiness for mechanization and robotics in the form of autonomous sprayers, robotic harvesters etc. There are further pressures including the cost of installation and availability of contractors to perform installation works. While trellising may be effective in different locations, the benefits have yet to be realised in WA and should be further investigated, especially from an economic point of view.

While the trellising results were unclear, the identification of plant material that is suitable under WA climatic conditions has been a success. Seedlings of C2 and CP47 were the most successful under nursery conditions, while seedlings of two local accessions, GUG and MOR, were notably more advanced in the field in Carnarvon. These four varieties are encouraging for the future diversification of jackfruit as a tropical crop. Future research should include understanding the genetics, clonal propagation, agronomy, fruit quality, and postharvest storage of these varieties.

Finally, the environmental challenges addressed during this project led to the implementation of different cultural practices and identified areas for future work. The management of irrigation, temperature, light, and disease are critical components of a resilient production system in WA. It was demonstrated that temperature and Phytophthora disease can be better controlled through precision irrigation practices, including frequent but minimal soil wetting during heatwave events. Early trial difficulties led to increased knowledge about seedling propagation, appropriate field planting, and the necessity of wind guards in WA. Additional research into orchard diversification and an agroecosystems approach, with companion cropping for light protection and orchard biodiversity, are worthy of exploration to address these challenges. Overall, the applied production method techniques gained during this project are useful to growers across the north and under a variety of crops.

Chapter 3: Northern Territory trial sites

Executive Summary

The “Demonstrating Next-Generation Resilient Orchard Production Systems for Tropical Crops” (next generation orchards) project was a 3-year project funded by the CRC for Developing Northern Australia (CRCNA). The project was led by Department of Agriculture and Fisheries (DAF) of the Queensland Government (Qld) and collaborators included the Department of Industry, Tourism and Trade (DITT) of the Northern Territory (NT) Government, Department of Primary Industries and Regional Development (DPIRD) of Western Australia (WA) Government, GrowCom (QFVG), NT Farmers Association Inc., Manbulloo LTD. and Aus-Ex Fruit.

The objectives of this project were to:

- Demonstrate and assess the validity/suitability of high-density plantings;
- Demonstrate and assess the use of support systems (e.g. trellis);
- Evaluate different production methodologies for planting material;
- Evaluate various jackfruit selections for commercial production;
- Provide the opportunity for the industry to see and understand the "Next Gen Orchard" production system

Diversification of crop production in northern Australia is crucial in developing an economically sustainable and resilient agricultural sector. Colloquially termed the 'Next Gen Orchard', high-density or trellis-supported orchards provide an alternative production system that commercial growers can use to improve operational performance. Jackfruit has exceptional production potential across the majority of northern Australia and was used as a model tree crop for the project to demonstrate these systems.

The production of nursery plants to grow the Australian jackfruit industry has traditionally been focussed on non-clonal seedling plants. These plants provide inconsistent outcomes in terms of fruit quality and timing of harvest, however alternative propagation methods have been challenging to grow successfully.

The key results were:

- The development of a tissue culture protocol for jackfruit propagation.
- Demonstration of high-density orchard design in the Northern Territory.
- Industry engagement with the trials.

DITT established a series of jackfruit propagation trials to evaluate different production which consistently highlighted the importance of disease control in mother plants. This project developed a Tissue Culture (TC) protocol for multiple lines of jackfruit, enabling the production of 15+ disease free plants from a single 1cm plant tip. Alternative vegetative techniques are unable to compare in terms of numbers of plants produced and the ability to screen *in-vitro* for healthy plants free of fungal and bacterial contamination.

A field trial was established at the NT Government’s Coastal Plains Research Farm (CPRF) to investigate orchard design and monitor the clones; and an additional grower partner site was established at a grower partner located at Katherine. These plants have not yet reached maturity and will be monitored for fruit set and yield until 2025/26.

DITT worked with the Territory growers’ organisation, NT Farmers, to provide industry extension via three field walks held at CPRF, along with associated social media content. With a cumulative audience of over 120 participants, these annual events were attended by growers from across northern Australia, researchers, industry organisations and university students. Social media posts shared throughout the life of the project garnered 5,000+ views.

Introduction



Figure 84. Jackfruit growing in Darwin, Australia.

Jackfruit (*Artocarpus heterophyllus*) is a tropical fruit tree, considered to be a major fruit crop in parts of Asia but still a developing industry in Australia. The arils and the seed of jackfruit can be consumed either raw (in the case of the arils) or cooked (arils and seed). There is increasing interest in this crop domestically as highlighted by the Coriolis – New Opportunities in New & Emerging Agricultural Industries in Australia report (RIRDC 2017). Cultivating jackfruit plants from seed has historically been the main means of propagation.

Whilst the project had overall themes in terms of field and propagation trials, each region undertook slightly different experimental trials. DITT undertook (1) propagation trials to identify effective vegetative propagation systems suitable for industry, (2) field trials to assess the performance of different propagule types (cuttings and grafted plants) in high density and trellised systems, (3) supervised a PhD student from Edith Cowan University (ECU) to undertake trials pre and post-harvest on the jackfruit variety Rajang, and (4) undertake grower engagement throughout the life of the project via field events and social media.

Propagation trials

In Australia, cultivating jackfruit plants from seed has historically been the main means of propagation. Unfortunately, this leads to wide variation in fruit size, shape, quality and colour of the edible arils, and harvest time. In contrast, vegetative propagation (such as grafting, cuttings and marcotts) ensures uniform flowering, fruiting, and consistent fruit quality parameters - important traits for high density, commercial plantings.

In general, jackfruit plants raised from seed start flowering at 2-8 years, whereas clonally propagated trees can produce fruit in as little as 2-4 years from planting. The plant has high levels of latex which is believed to interfere with callus development and a strongly bonded graft union, making it challenging to reproduce vegetatively. There is a substantial body of research on the vegetative propagation of jackfruit conducted worldwide; briefly summarised below. No single method has been found to be consistently successful in all the trials. Along with the high concentration of latex, the interaction of regional diversity, weather, seasonality, and the "variety" of trials may potentially be a significant factor in the absence of consistent results.

Field trials

Commercial Australian jackfruit production is predominantly based on non-clonal, low density, seedling orchards. These orchards are characterised by large canopies, and a lack of uniformity in fruit timing, production, and quality. Large jackfruit trees bear fruit that is unable to be reached without a cherry picker, ultimately these fruits are left to rot in the field, contributing to food waste, attracting vertebrate pests and accumulating disease inoculum. Intensification of jackfruit plantings, including higher density, smaller canopy trees may provide many benefits such as a more manageable plant, all harvestable fruit within reach, greater penetration of chemicals into the canopy, reduced fruit waste and reduced disease inoculum. This project demonstrated the intensification of jackfruit orchards through high density and trellised plantings to support the decision-making of northern Australian producers.

Objectives

The key objective of the overall project was to demonstrate the benefits of the 'Next Gen Orchard' to the tropical fruit industry using jackfruit as the model crop:

1. Demonstrate and assess the validity/suitability of high-density plantings and identify opportunities and constraints associated with high-density plantings through field trials;

2. Demonstrate and assess the use of support systems (e.g. trellis);
3. Evaluate various jackfruit selections for commercial production in the field trials;
4. Evaluate different propagule types (cuttings, grafted plants etc.) in the field plantings
5. Evaluate different production methodologies for planting material through propagation trials.
6. Provide the opportunity for the industry to see and understand the "Next Gen Orchard" production system; and provide opportunities for knowledge sharing across the industry.

Methods

Plant nursery facility

Whilst a number of different potting media mixes were used throughout the propagation trials, the main media for established potted plants was 1:1 coir to wood chip media with a small amount of trace elements. Potting media was bulk sterilised at 60°C before use.

Cuttings and de-flasked TC plants were kept in a mist house with irrigation set to 10 seconds every 2 minutes. Grafted plants, seed trays, and established TC plants were maintained in a shade house with irrigation scheduled daily.

Propagation trials

Various propagation techniques were trialled throughout the course of the project including seeds, cuttings, aeroponics, grafting, marcotting and TC, as evidenced in Figure 85 below.



Figure 85: The propagation trials included a variety of techniques, including growing from seeds (A), cuttings (B), aeroponics (C), grafting (D), marcotts (E), and tissue culture (micro-propagation) (F).

i. Seed germination

Seed were removed from healthy, freshly harvested fruit from the CPRF orchard, rinsed in tap water and stored for up to one week in refrigeration. Prior to planting, the outer case of the seed was removed. The seed was planted in seedling trays with a 1:1 coir to wood chip media ratio. Once the seedlings reached 3-4 inches high, they were replanted into individual pots of the same media. Success rate was calculated as the number of surviving propagules.

ii. Cuttings and aeroponics

A variety of treatments were trialled in this activity, including:

- Age of planting material (hardwood or semi-hardwood)
- +/- plant hormone (IBA and NAA)
- +/- sterilising agent (Nylate™ or fungicide Scholar®)
- Media type (florists' foam, coir plugs, general media, sand, perlite/vermiculite mix)

All treatments utilised jackfruit cuttings of 5-10mm diameter. Cuttings were taken first thing in the morning before transportation back to the nursery head house at the BFSP for treatment and planting. Trials utilised planting material from four different accessions of jackfruit. Each treatment consisted of 15 randomly assigned cuttings. Cuttings were rinsed individually in clean water and left to air dry briefly. All leaves, excepting the top 4 were removed from the cutting. Those treatments with a sterilising agent (either Scholar® or Nylate™) were soaked in the sterilising agent for 10 minutes. Plant hormones treatments were applied as a dip prior to planting. Success rate was calculated as the number of surviving propagules. Success rate was calculated as the number of surviving propagules.

As shown in Figure 85C, aeroponic chambers were set up to observe the development of roots in response to the different hormone treatments. The aeroponics trials utilised a mixture of:

- +/- plant hormone (FloraMax™, Cyclone, IBA)
- +/- sterilising agent (Nylate™)

Consistent with the other cutting treatments, jackfruit cuttings of 5-10mm diameter were taken first thing in the morning before transportation back to the nursery head house at the Berrimah Farm Science Precinct (BFSP) for treatment and planting. Cuttings were rinsed individually in clean water and left to air dry briefly. All leaves, excepting the top 4 were removed from the cutting.

Nylate™ was applied via soaking for 10 minutes. Plant hormones were applied to the water reservoir which was rinsed and cleaned weekly. Plants were observed daily for root callousing/initiation. Each treatment was carried out in a single chamber containing 24 randomly assigned cuttings. Success rate was calculated as the number of propagules transplanted into pots.

iii. Marcotts

Mother plants were selected from healthy individuals at CPRF. Using a sterilised blade two concentric rings were cut into the jackfruit branch and the bark removed to remove the cambium layer (Figure 86).

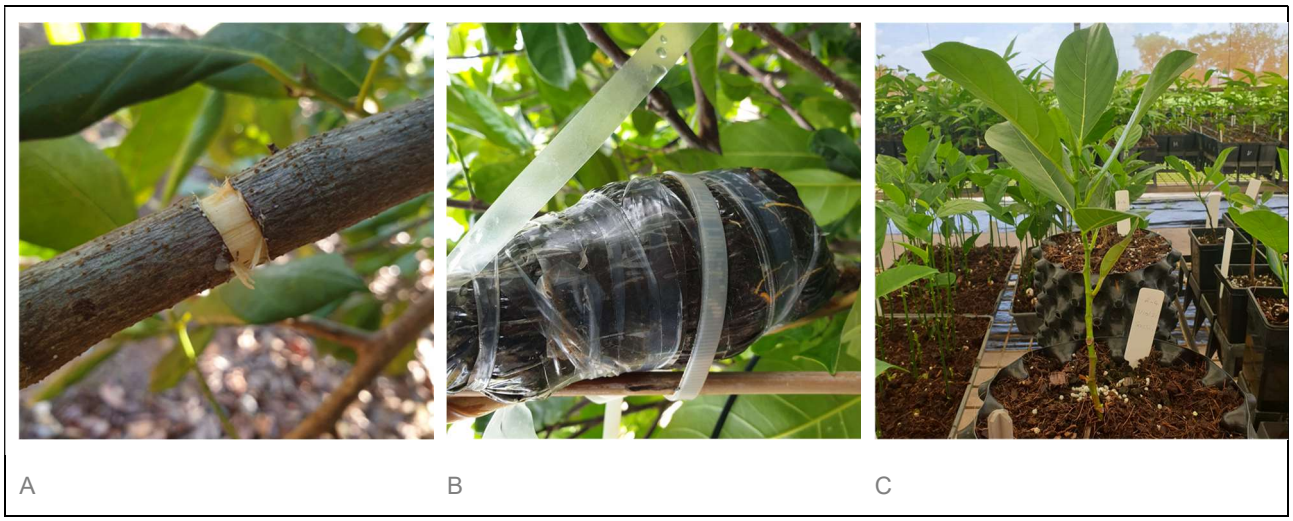


Figure 86. The process of marcotting jackfruit plants from cincturing the branch stem (A), monitoring for root growth (B) and then planting out the propagule (C).

The wound was covered with moist media and sealed with a transparent plastic bag. Once root growth was visible, the marcott was removed from the mother plant, transported to the nursery facility, and potted up. Success rate was calculated as the number of surviving propagules.

iv. Grafted plants

A variety of treatments were trialled in this activity, including:

- +/- sterilising agent (Scholar®, Nylate™)
- Age of rootstock (3 months old grown from seed, 1 month old grown from seed)
- Graft type (splice, wedge)
- Accession used for scion material.

Rootstocks were grown from seeds as described above and maintained in a shade house with regular irrigation. Scion material taken first thing in the morning before transportation back to the nursery head house at BFSP. Trials utilised scion material from four different accessions of jackfruit. Each treatment consisted of 15 randomly assigned cuttings. Cuttings were rinsed individually in clean water and left to air dry briefly. All leaves, excepting the top three were removed from the cutting. Those treatments with a sterilising agent (either Scholar® or Nylate™) were soaked in the sterilising agent for 10 minutes.

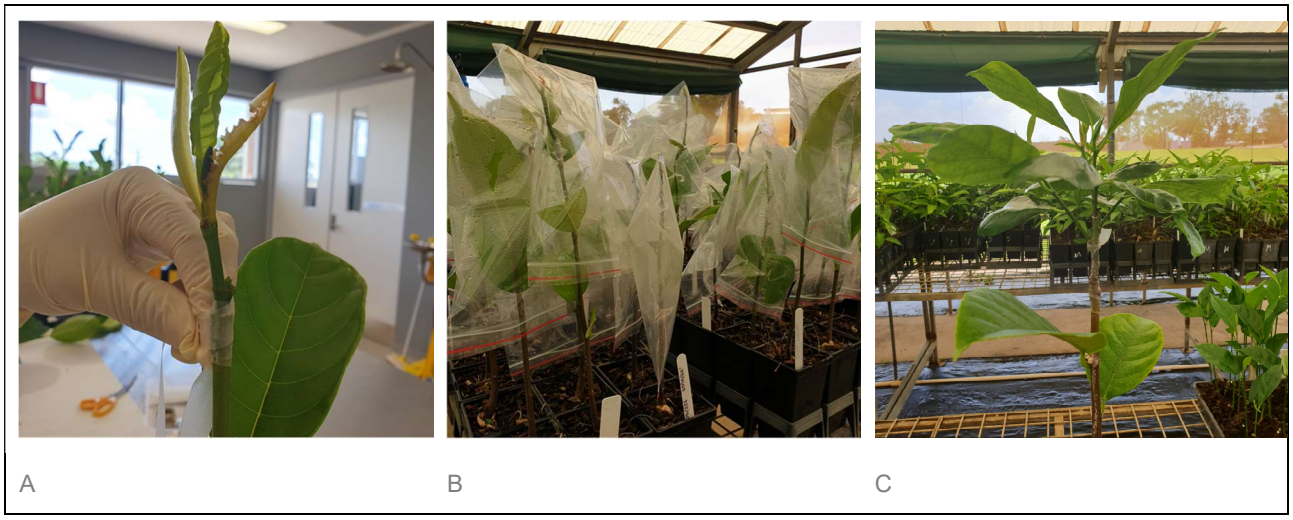


Figure 87. Grafting plants (A), plants were kept in the nursery facility until established (B). Successful grafts were repotted into larger containers (C).

Grafting was carried out using sterilised scalpels and sealed with paraffin wax tape. Plants were covered with transparent plastic bags initially, once the graft union was healed the bags were removed and the plants repotted (Figure 87). Success rate was calculated as the number of surviving propagules.

v. Inoculum trial

Healthy cuttings were obtained from three mother individual plants at CPRF. For each plant, the cuttings were held in a sterilised bucket with approximately 1L of water to prevent dehydration in-transit. The water was agitated and a 5mL aliquot of water was sampled from the buckets hourly at 1, 2, 3, 4, 5 and 24 hours, placed into a sterilised sample jar and vortexed to ensure an even distribution. A 10µL subsample of the water was aliquoted onto sterile Potato Dextrose Agar (PDA), before incubating in the dark at 25°C for 24 hours. At 24 hours, the number of bacterial and fungal culture colonies on each plate were assessed.

vi. Tissue Culture (TC)

The TC trials assessed several different accessions against a DITT standardised TC protocol. The protocol was then refined in terms of sterilisation techniques, hormone concentrations etc. to promote healthy root and shoot growth. The protocol is currently in the process of being published and will not be detailed in this report.

Field trials

Grower partner

94 plants were provided to grower partner, Manbulloo, on September 1st 2021 as part of their plantings, couriered by NT Farmers officer Greg Owens. These plants were planted out as a part of their larger jackfruit trial on one of their commercial orchards in Katherine, NT.

CPRF high density and trellised trial

Jackfruit high density and trellised trials were planted at CPRF on January 5th 2022. The early January planting was chosen to minimise risk during the NT Government's Christmas closure from December 25th until January 4th, during which time there would be no staff in the field to monitor the plants.

The plants in the field trial were divided into two groups, each with 54 plants, as shown in Figure 88 below. The first group had two rows of high-density plantings at 6m x 3m spacing, while the second group had two rows of trellised plants at the same spacing. The high-density trial comprised three accessions (310, 341 and 348) with both grafted propagules (G) and cuttings. The trellised plants comprised two accessions (310 and 326).

		R1 (Trial)	R2 (Trial)	Trellis R1	Trellis R2
		Road			
T1		341 G	348G	310	326
T2		341 G	348G	310	326
T3		341 G	348G	310	326
T4		348G	341G	310	326
T5		348G	341G	310	326
T6		348G	341G	310	326
T7		310G	310	310	326
T8		310G	310	310	326
T9		310G	341	310	326
T10		348	341	310	326
T11		348	341	310	326
T12	GUARD ROW	348	348	310	326
T13		310	348	310	326
T14		310	348	310	326
T15		310	310G	310	326
T16		341	310G	310	326
T17		341	310G	310	326
T18		341	341	310	326
T19		348	341G	310	326
T20		348	341G	310	326
T21		348	341G	310	326
T22		310	348G	310	326
T23		310	348G	310	326
T24		310	348G	310	326
T25		341	310G	310	326
T26		341	310G	310	326
T27		341	310G	310	326

Figure 88: Field plan of the trellised and high-density planting at CPRF.

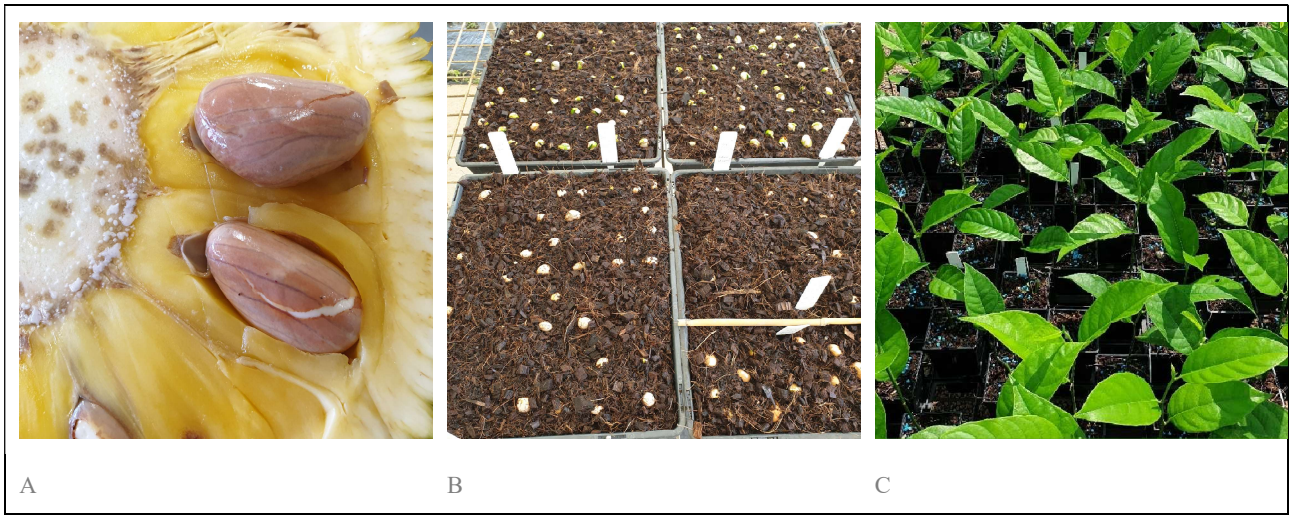
Results and discussion

Propagation

i. Seed germination

Individual fruit can contain between 100-500 seeds, making mass propagation from seeds a simple process. The major harvest period for jackfruit varies depending on the region and country. Seed propagation is most effective from freshly harvested fruit, as opposed to seed that has been stored for a period (Abd El-Zaher, 2008). The most successful results for seed germination come from a combination of treatments, specifically de-coating the seed, soaking them for 12 hours in water, and applying 10 ppm Gibberellic Acid (GA), and 100 ppm of kinetin (Abd El-Zaher, 2008). Kinetin is a plant hormone known to promote cellular division, commonly used in tissue culture to induce the formation of a callus. GA is another plant hormone involved in regulating germination and dormancy, it has a thinning effect when sprayed on grape flowers, but increases berry size when used on grapevine fruit.

As shown in Figure 89 below, this activity initially trialled freshly harvested seeds (used within 1 week of harvest) without soaking or plant hormones, with a success rate of 90%. No further treatments were considered necessary.



A B C

Figure 89: Seedling propagation was carried out using freshly harvested fruit (A) seeds were planted into trays of media (B). Once they reached 3-4 inches tall, they were transplanted into individual pots (C).

The success might be attributed to the use of fresh seed and the removal of the outer coat, which is considered critical (Abd El-Zaher, 2008).

ii. Cuttings and aeroponics

Multiple studies have found little or no success in rooting jackfruit cuttings without Indole-3-butyric acid (IBA) (Biswas & Kobayashi, 1995; Dhar, 1998; Mukherjee and Chatterjee, 1979). IBA is a plant-based hormone commonly used to promote root development. Other commonly used plant hormones associated with root promotion are Indole-3-acetic acid (IAA) and naphthyl acetic acid (NAA). International research suggests that combinations of branch cincturing and IBA, NAA or IAA, and etiolation may significantly improve outcomes (Biswas & Kobayashi, 1995; Dhar, 1998; Mukherjee and Chatterjee, 1979).

Over 2,000 cuttings were trialled across various treatments including accession, media type, age of the plant material, hormones, and disinfectants. To simplify the matrix of treatments and outcomes the flow diagram below (Figure 90) represents the various treatments for those decision trees which led to a level of propagation success. Florists foam and coir plugs resulted in the rapid decline of all propagules, additionally all early trials which omitted Scholar® resulted in early failure. Successful propagation attempts used a well-drained mix of 1:1 perlite to vermiculite, or coarse sand with a mixture of plant hormones.

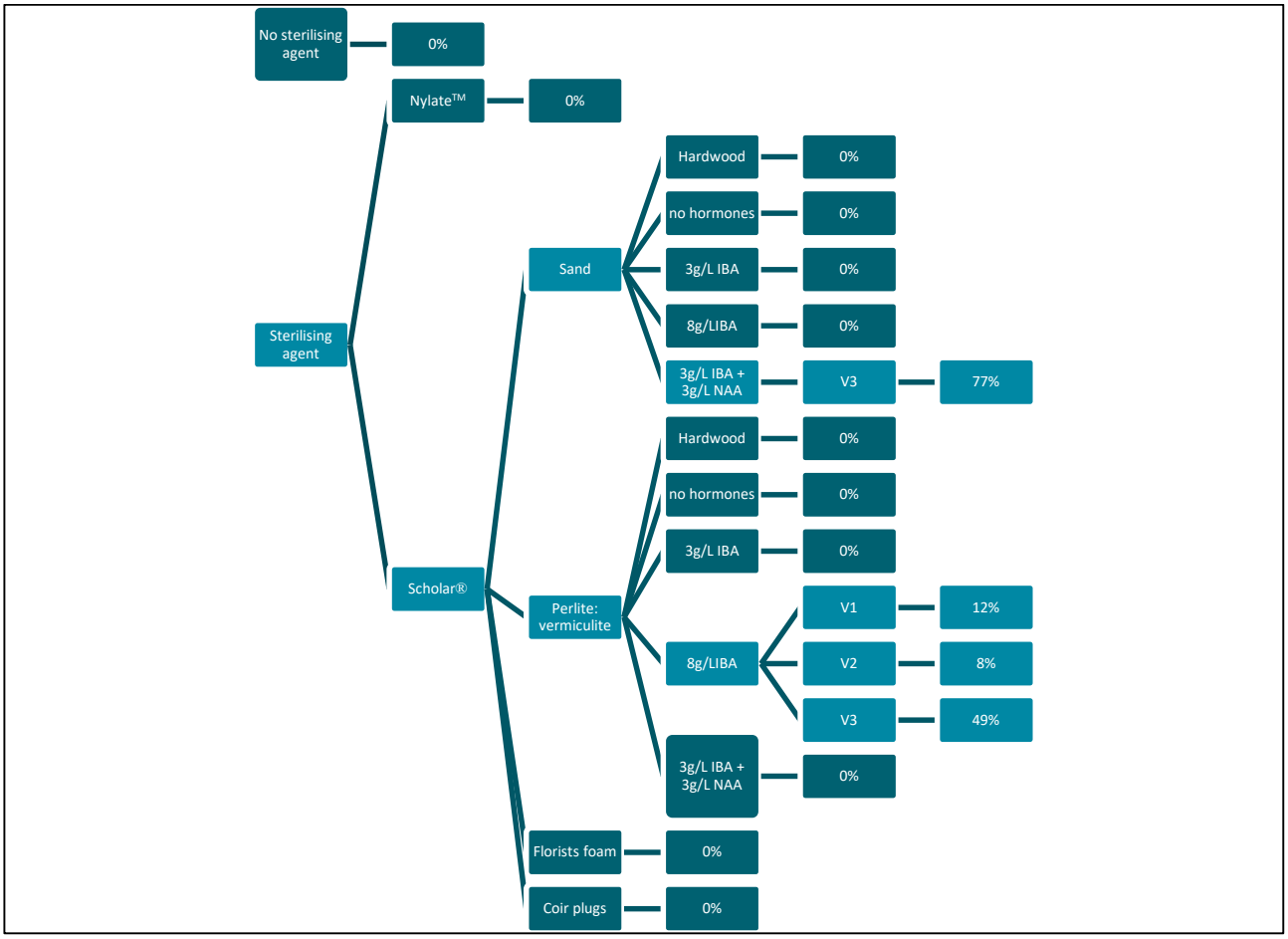


Figure 90: Flow diagram representing the various treatments trialled for propagation of jackfruit via cuttings. The Nylate™ and the "no sterilising agent" flows have been reduced for the sake of brevity. Like the Scholar® treatment, they included a full suite of media, hormone and variety treatments, of which none were successful. Different accessions are identified as "V1", "V2" and "V3".

The aeroponics capsules regularly mist the cuttings with a mixture of hormones and water. The capsules allow easy removal of the lid and the plants from the water reservoir aiding observations of root development without damaging the propagule by removing it from the soil. This provided more detailed exploration of the root callousing an initiation (Table 2).

Table 2. Root callousing and replanting success rates for jackfruit cuttings in aeroponic chambers.

Treatment	Root callousing @ 1 week	Successfully replanted
FloraMax™ + Nylate™	69	29%
Cyclone + Nylate™	70	13%
FloraMax™	4	0%
Cyclone	4	0%

The aeroponics trial showed high levels (~70%) of root callousing after one week with either hormone treatment (FloraMax™ or Cyclone). However, the cuttings declined slowly from rots with only 29% successfully grown through replanting using FloraMax™ and 13% using Cyclone. Treatments without Nylate™ rapidly declined from rot.

This continued the consistent theme across all the cutting treatments indicating high levels of contamination in the mother plants. Given that there are limited fungicide options registered for jackfruit in Australia, investigations into the inoculum loads in the mother plants was prioritised.

iii. Marcotts

Marcotting (otherwise known as air layering) is sometimes used as an alternative to traditional cuttings when the success rate for the latter is low. Rooting is affected by light, moisture and temperature, seasonal differences affect the outcome. In fact, one study found the seasonal effect accounted for an 18% difference in success rates. Similarly to cuttings, research on marcotting found minimal success without the use of hormones such as IBA, IAA or NAA (Dhar, 1998; Mukherjee & Chetterjee, 1979; Singh & Singh, 2004; Tomar, 2011; Ezekiel et al., 2016).

The marcott trial had a success rate of 40%, slightly lower than the rate for grafted propagules, and in-line with international literature. More problematic than the success rate, marcotting is not an effective method of mass production. This technique requires the removal of the branch from the cincture down. This limits the number of marcotts that can be grown on a single mother plant quite drastically when compared to other techniques such as TC, which require only 1-2cm of vegetative material to grow 15 plants.

vii. Grafted plants

There is a fair body of work assessing grafting techniques for jackfruit, however the success rates vary dramatically between studies and treatments. Potential causes of failure for grafting include scion/rootstock incompatibility, drying out of the graft union, poorly fitted graft union (where the cambium layers from the scion and rootstock don't line up), latent disease, pathogens invading the wounded site (Abd El-Zaher, 2008; Aralikatti et al., 2011; Biswas & Kobayashi. 1995; Basalo & Lina, 2020; Das, 2013; Desai & Desai, 1989; Haq, 2003; Harshavardhan et al., 2011; Islam et al., 2004; Islam et al., 2003; Khatun et al., 2006; Konhar et al., 1990; Mannan et al., 2006).

Over 200 plants were grafted, using various grafting techniques, age of planting material and disinfectant. To simplify the matrix of treatments and outcomes the flow diagram below (Figure 91) represents the various treatments for those decision trees which led to a level of propagation success.

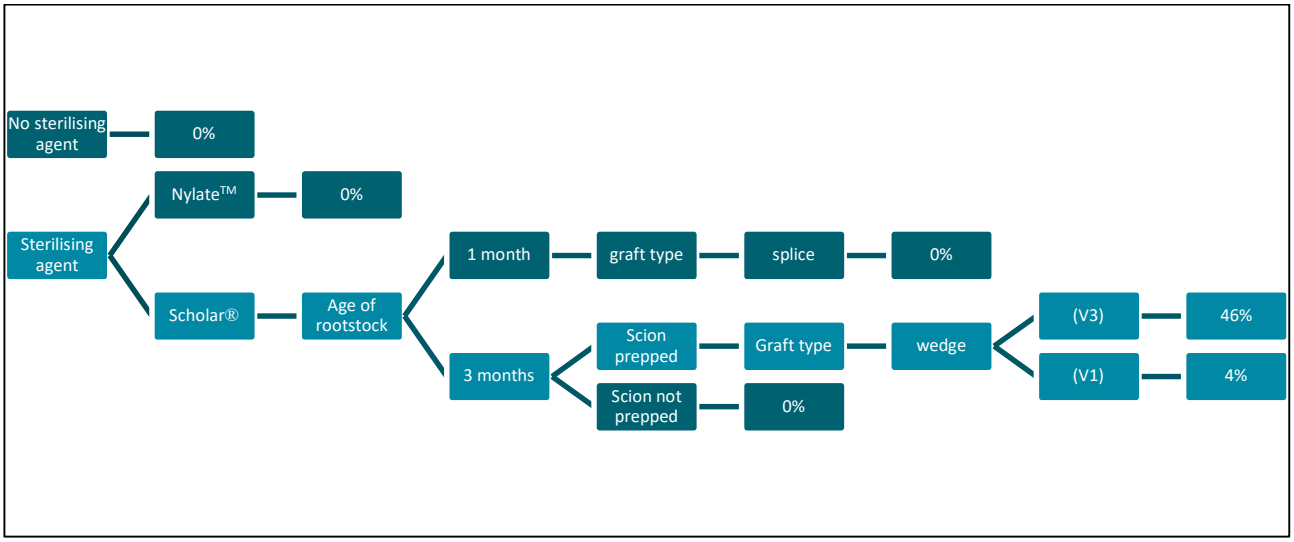


Figure 91: Flow diagram of the various grafting treatments and outcomes. The highest survival rate was 46%.

The results for the grafting trials found moderate levels of success with disinfested scion material wedge grafted to three-month-old rootstocks. Scion material prepared by etiolation two weeks prior to harvesting was more successful than unprepared scion material. A success rate of 46% is in line with the international literature, however once again the results required the use of a fungicide to be successful.

v. Inoculum trial

Several cosmopolitan fungi which can cause latent disease issues in mangoes and grapevine grafting are present in jackfruit (Awasthi et al., 2005; Haque et al., 2005; Medina Tiznado et al., 2018; Ni et al., 2008; Rashid et al., 2015; Slippers et al., 29; Trakunyingcharoen et al., 2014). Hygiene and plant health are critical components of the vegetative propagation of plants, particularly grafting. This includes selecting pest and disease-free scion and rootstock material, harvesting scion material in optimal conditions and regularly sterilising tools and surfaces to reduce cross-contamination (Aroca et al., 2010; Retief et al., 2006; Whiteman et al., 2004).

Early results from the propagation studies, consistently revealed a similar theme: propagules need a measure of sterilisation to succeed. Considering that the project is looking at strategies to increase mass production of jackfruit for commercial objectives, understanding the points of contamination is an important aspect of propagation. Contamination is an industry issue in several other commercial crops which rely on vegetative propagation, such as the grapevine industry

(Aroca et al., 2010; Retief et al., 2006; Waite et al., 2013; Whiteman et al., 2004). It is a common nursery practice to soak cuttings in water prior to propagation to reduce the risk of dehydration. In the grapevine industry this practice has been found to be a significant source of cross contamination for pathogens after as little as 1 hour (Waite et al., 2013). Unthrifty mother plants impact on the success, health and yield of any propagules and are a potential source of disease transmission between farms, regions, and countries.

There were high levels of variation in the amount of contamination from the individual mother plants, the rate of increase in colonies over time made it impossible to differentiate individual colonies after five hours. The results below in Figure 92 show only the average colony counts for 1 to 6 hours, results for samples at 6 and 24 hours are not included in this data.

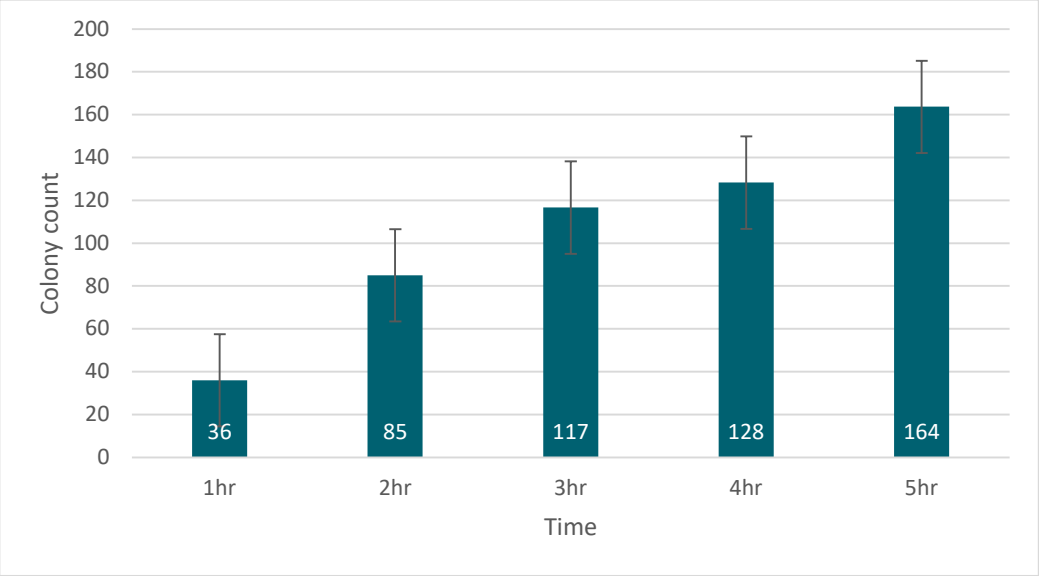


Figure 92: Average contamination over time from buckets of water holding cuttings from jackfruit plants.

The rate of contamination increased significantly over time, after 5 hours there were an average of 164 colonies cultured from the 10µL subsample of water. Given that there are 1 million microliters to the litre, this data suggests there is a high risk of cross contamination between individual jackfruit cuttings held in buckets of water, particularly if material from multiple mother plants are held in a single repository bucket. Informal discussions with local growers suggest that the build-up of disease inoculum in older jackfruit plants is a common problem in the NT due to the environmental conditions and the limited chemical controls permitted for use on jackfruit in the NT.

This aligns with the results from the grafting and cutting trials described above, high levels of pathogenic organisms within the orchard, coupled with limited chemical controls leads to low success in vegetative propagation activities. None of the grafted or cutting techniques trialled were successful without a sterilising agent. Any vegetative propagation from NT stock needs to focus on disease reduction or elimination to ensure healthy, disease-free plants.

vi. Tissue Culture

Successive research and extension from Australian industries such as ginger, banana, and papaya reflect the growing awareness of the importance of clean, disease-free planting material. Some of the most devastating plant diseases internationally are spread, unintentionally, through unhealthy propagative material including seeds, and cuttings. TC is an established technology that can ensure plantlets are free of both bacterial and fungal pathogens, even when the infections are not visible.

This technology is particularly useful for the mass propagation of plants, in comparison to other vegetative propagation methods. A small amount of mother plant material (1-3cm) can be utilised to grow tens to hundreds of plants (dependent upon the crop and the methodology).

According to the TC protocol, our team was able to generate up to 15 explants per tip at the BFSP, as evidenced in Figure 93 below. To date, we have successfully de-flasked more than 50 plants with fully developed roots. With the refined rooting medium we are using, we have observed a significant improvement, with 9 out of 10 plants producing fully developed roots.

Table 3. Summary of time frames for the various stages of TC of jackfruit

Stage	Time frame
Shoot initiation	8 weeks
Growth	8-10 weeks
Root initiation	4-6 months

However, it is worth noting that the process remains time-intensive, as summarised in Table 3, root initiation and growth alone takes approximately 4-6 months.

At this point, the nursery trials have not yet yielded successful results. We currently have over 200 explants in the lab, which have been callusing at the bottom and will undertake nursery trials on these explants from September 2024 onwards.

This is a highly promising technology, as it enables the production of disease-free clonal plants on a large scale for the future growth of the industry. The team plans to publish the TC protocol. A private TC facility in Australia has shown interest in using the protocol for commercial plant production.

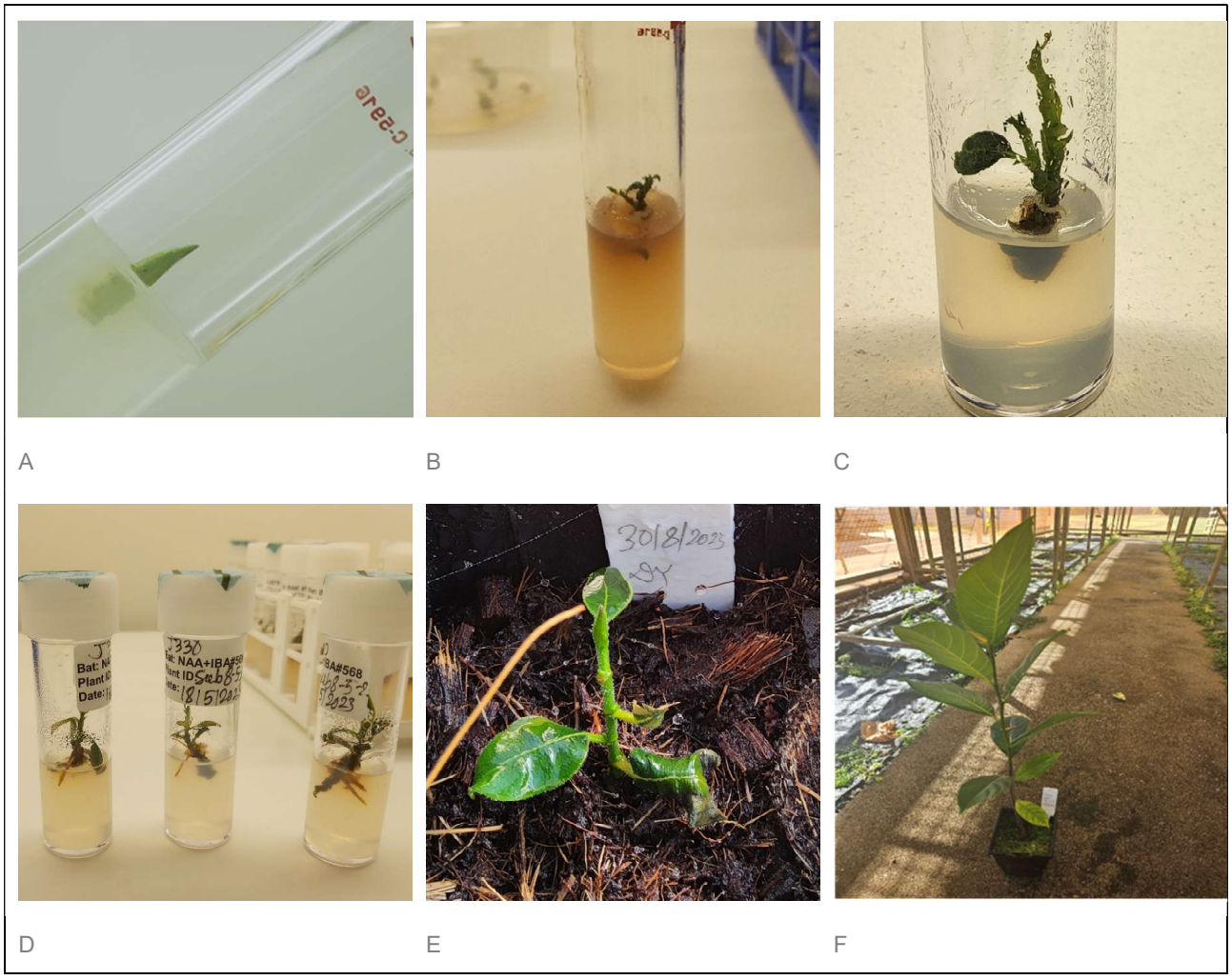


Figure 93. The TC protocol uses a single jackfruit tip (A) to produce up to 15 plants. High disease loads in the orchard led to high levels of contamination in stage 1 of the process (B). By 2023 the contamination issue was resolved through an additional decontamination step (C). Root initiation was difficult to refine due to phenolics, however this was resolved, and the methodology replicated in 2023 (D). The first TC plants were de-flasked in 2023 (E) and grown in the Berrimah Farm Science Precinct nursery (F).

It is important to note that these plants have not yet been trialled in the field. Future field trials will determine whether they (TC plants) form acceptable root systems in the orchard setting, and whether their yields are comparable to traditional

propagation techniques. Additionally, TC plants often take slightly longer to reach productive maturity, so timing to full maturity will need to be confirmed.

Field trials

Growth and performance of field trials

As shown in Figure 94 below, the jackfruit accessions planted at CPRF demonstrated vigorous growth during the project, but no fruit set.



Figure 94. The high-density field trial was planted in early 2022 (A), as was the trellised trial (B). By 2023 there were clear differences in the growth and habit of the different accessions in the high-density trial (C), the accession chosen for the trellised trial had a smaller growth habit (D). By 2024 the plants were being top pruned annually to maintain their compact size and shape (E), the trellised plants experienced growth spurts corresponding with the monsoon (F). Plants in the high-density trial are currently maintained at 3m high (G).

Plants were pruned annually to 3m high from 2023, limiting growth measurements to trunk circumference at 1m. The growth trends between propagule type (grafted and cuttings) differed between time points and is not conclusive at this stage. However, these plants are not yet at full maturity and will continue to be monitored until 2026. The most recent measure from April 2024 is provided below in Figure 95, showing a growth reduction in grafted propagules for two of the three accessions.

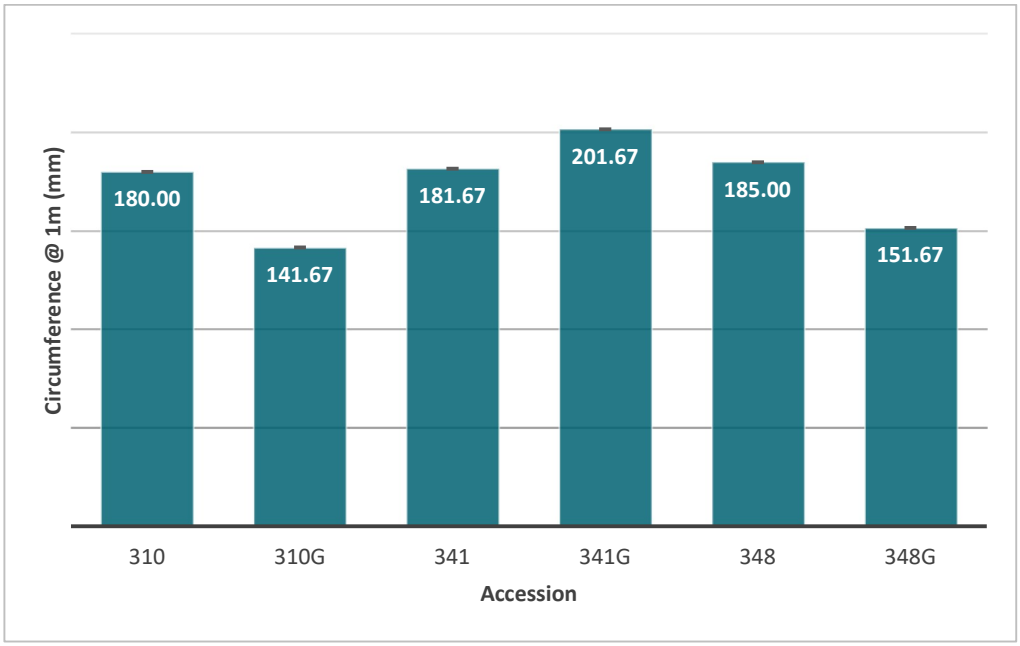


Figure 95: Average trunk circumference of high-density plants, 27 months after planting (April 2024) for cutting and grafted (G) jackfruit plants from three accessions (310, 341, 348).

Pests and diseases

There were minor pest and disease issues within the field trial, a small number of plants (3) were killed by termites, prompting the installation of termite baiting stations (Figure 96). Samples of the termites were sent to the entomology branch; this species are known to be locally endemic and only problematic in small plants and fence posts.



Figure 96. There were some minor pests and diseases encountered in the CPRF trial over the life of the project, including termites in the soil of the jackfruit high density trial (A), this was resolved with a baiting station to monitor for termite presence placed in the ground at CPRF (B). There was considerable defoliation (C) of smaller plants due to swarming beetles *Rhyparida* sp. (D).

Swarming beetles, *Rhyparida* sp., were seasonally abundant in all jackfruit plants at CPRF (Figure 96). These locally endemic pests cluster together in protected sections of the foliage and chew the leaves and growing tips on new flush. The damage has less impact on mature plants but did cause severe defoliation to several younger plants.

Grower partner

The Katherine grower partner plants experienced significant issues with wallaby damage as shown in Figure 97. The plants experienced significant chewing damage along their trunks, allowing secondary infections and causing heavy callusing. A number of different techniques were used to try to reduce the access of the wallabies, including the use of milk crates to “cage” smaller plants and fencing.



Figure 97. Plants at Katherine experienced significant wallaby damage to the trunks.

The plants flowered during 2023 and bore a small amount of fruit which was harvested and assessed by PhD student Jashan Kaur at the DITT post-harvest laboratory. Farm management allowed the flowers to set fruit to reduce the vigour of the plants and to establish a fruiting pattern for the trees, in line with their general practice.

PhD project (governance)

As part of the initial request for proposals, DITT and ECU submitted a proposal for a PhD student to undertake research on postharvest aspects of jackfruit. The CRCNA combined the Next Gen Orchards project with the PhD proposal to improve collaboration and drive governance and administration efficiencies. The PhD sub-contracting and reporting is managed through DITT rather than Qld DAF.

The PhD candidate, Ms Jashanpreet Kaur, started her candidature in March 2022. Ms. Kaur was based at DITT's Berrimah Farm Science Precinct (BFSP) for much of her project, for the convenience of access to fruit for her experiments. During her stay with DITT, she visited Coastal Plains Research Farm (CPRF) and local growers to collect Rajang fruit for her experiments. These fruits were destructively sampled in the lab and the fruit tissues stored at -20°C for further analysis at the ECU laboratory. Ms. Kaur returned to ECU in early 2024 to undertake the laboratory analysis of her samples. Ms. Kaur submitted 6 monthly reports on her experimental plans and progress throughout the project, her 3rd year (final) report was submitted in April 2024 (Milestone 89). She has published two scientific journal articles on the topic listed below in the outputs section.

Extension and engagement



Figure 98. CPRF field day 2023

Stakeholders

The project and associated deliverables are targeted to the agricultural industry, primarily existing tropical fruit growers such as those who commercially cultivate rambutan, longan, durian, mangoes and jackfruit.

Communication channels

Content for the Next Gen Orchards project was shared on the AgricultureNT Facebook page. This is a public group administered by DITT with over 1,300 members (as of August 2024). Membership spans from growers, researchers, industry organisations, students and the general public. Posts were then shared on the Next Gen Resilient Orchards Facebook page.

Field walks were held annually at CPRF, allowing visitors to walk through the trellised and high-density trial. Project members from Queensland, Western Australia and Edith Cowan University attended at least one of the field walks and spoke to the projects progress in their regions.

The NT DITT Agriculture and Biosecurity newsletter (formerly known as the NT Rural Review) is a bi-monthly, subscription based e-newsletter targeting growers, researchers, industry organisations, students and the general public.

Issues

COVID

COVID cases climbed in the NT after the borders opened in December 2021, resulting in the isolation of various staff in line with the Chief Health Officer directions. DITT maintained an active COVID management plan to ensure business continuity and minimise disruption as much as possible. There was some COVID based disruption to scheduling events, as well as general discomfort from growers and the public in physically attending events in early 2022. DITT and the NT Farmers held a field event in May 2022.

Outputs

Over the life of the project DITT hosted annual field walks and posted a number of communications and social media. Specific details can be found in Table 2 below, and evidence (photographic and screen shots) in Appendix E, including the scientific research articles by Ms. Kaur.

Table 4: Outputs and extension activities from NT DITT

Item	Channel	Date(s)	Detail
2022 Field walk	Field walk	13/5/2022	Approximately 30 people attended the event, including growers, researchers, associated organisations (commercial agents and organisations) from across northern Australia.
2023 Field walk	Field walk	26/5/2023	The 2023 field walk was attended by around 80 people, including students, growers, other agencies, and representatives from funding organisations.
2024 Field walk	Field walk	9/5/2024	Approximately 25 attendees, including local jackfruit and tropical exotic fruit growers, and NT Farmers representatives attended the event.
Social media	Online posts to AgricultureNT Facebook page and/or shared with the CRCNA Next Gen project Facebook page.	Ongoing through the life of the project.	Social media posts were made throughout the life of the project ranging from invitations to the field walk to updates from the field (see Appendix E for screen shots of individual posts). The 12 posts on AgricultureNT amassed a cumulative post reach of 5,793. Post reach is defined as the number of people who saw the post at least once.
Short review of propagation	Internal project information provided to Qld DAF and CRCNA		A short internal review of the international literature regarding vegetative propagation of jackfruit.
Internal PhD reports	Confidential reports to Qld DAF and CRCNA	Ongoing through the life of the project.	PhD updates were provided regularly throughout the project, including Ms. Kaur's literature review, planned experimental trials and annual progress reports.
Jackfruit TC protocol	{currently awaiting publication}	Expected late 2024/ early 2025	The jackfruit TC protocol will be published online.
Scientific article (PhD student)	Scientific article on jackfruit phytonutrients	2023	Kaur, Jashanpreet & Singh, Zora & Shah, Hafiz & Mazhar, Muhammad & Hasan, Mahmood & Woodward, Andrew. (2023). Insight into phytonutrient profile and postharvest quality management of jackfruit. Critical Reviews in Food Science and Nutrition. 64. 10.1080/10408398.2023.2174947.
Scientific article (PhD student)	Scientific article on jackfruit mineral profile.	2024	Kaur, Jashanpreet & Singh, Zora & Mazhar, Muhammad & Afrifa-Yamoah, Ebenezer & Sangha, Kamaljit & Woodward, Andrew. (2024). Mineral profiling of diverse genotypes of jackfruit (Artocarpus heterophyllus Lam.) grown in Australia. Journal of Food Composition and Analysis. 135. 106599. 10.1016/j.jfca.2024.106599.
Newsletter article	NT DITT newsletter	11/2021	Demonstrating next-gen resilient orchard production systems for tropical crops- project launch (link)

References

Abd El-Zaher M.H (2008). Using the Grafting for Propagation of the Jackfruit and Producing the Rootstocks for the Grafting. American-Eurasian J. Agric. & Environ. Sci., 3 (3): 459-473.

Aralikatti, G.; Mokashi, A.N.; Hegde, R.; Patil, R.; Angadi, S.G. (2011). Softwood grafting in jackfruit. Acta Horticulturae. 890: 101-106.

Aroca A.D.; Gramaje, J.; Armengol, J.G.J.; Raposo, R. (2010). Evaluation of the grapevine nursery propagation process as a source of Phaeoacremonium spp. and Phaeomoniella chlamydospora and occurrence of trunk disease pathogens in rootstock mother vines in Spain. European Journal of Plant Pathology 126: 165–17.

Awasthi D. P.; Sarkar S.; Mishra N. K.; Kaiser S. A. K. M. (2005). Disease situation of some major fruit crops in new alluvial plains of West Bengal. Environment and Ecology 23: 497-499.

Basalo, J.A.; Lina, D.P. (2020). Enhancing Graft-Take Success in Jackfruit (*Artocarpus heterophyllus* Lam.) Var. "EVIARC Sweet" Seedlings by Pre-Grafting Treatments. Mindanao Journal of Science and Tech. 19 (1): 1-15.

Biswas, M.; Kobayashi, K.D (1995). Girdling, wounding, stem maturity, and IBA effects on rooting of jackfruit stem cuttings Journal of Hawaiian Pacific Agriculture 6: 19- 25.

Das S.C. (2013). Standardisation of softwood grafting of jackfruit under Tripura conditions. The Asian J. of Hort. 8 (2): 409-413.

Desai, S.A.; Desai, A.G. (1989). Effect of age, length, defoliation and storage of scion sticks on success of softwood grafting in jackfruit (*Artocarpus heterophyllus* Lam). Proc. Indian Acad. Sci. (Plant Sci.) 99: 585–591.

Dhar, M. (1998). Techniques of vegetative and in vitro propagation of jackfruit. Ph.D. Thesis, Institute of Postgraduate Studies in Agriculture. Salna. Gazipur, Bangladesh.

Dickinson, G.R.; Bennett, D.M.; Bally, I.S.E.; Orr, R.; Empson, M.; Quddus, S.; Robson, A.J.; Walsh., K.B. (2023). Facilitating industry adoption of intensive mango practices and new ag-technologies in Australia. Acta Horticulturae (in press). Proceedings of the XIII International Mango Symposium, Malaga, Spain, 29 September – 3 October 2023.

Enderlin, N.G. (1997). Mareeba Dimbulah irrigation area soil sheets. Queensland Department of Natural Resources and Mines.

Ezekiel, R.; Bikash, G.; Devi, H.L (2016). Effect of different seasons of air layering on success percentage and other growth attributes of Jackfruit under Eastern India. The Bioscan 11(4): 2703-2706.

Haq, N. (2003). Improvement of Underutilized Fruits in Asia. Final Report. Community Fund, UK.

Haque, M.; Mridha, A.; Bhuiyan M.K.; Huda, S.; Uddin M.B. (2005). Studies on the Occurrence and Severity of Leaf blight of Jackfruit (Artocarpus heterophyllus Lam.) caused by Botryodiplodia theobromae. Journal of Mycopathological Research. 43: 91-94.

Harshavardhan, A.; Rajasekhar M.; Reddy, P.S.S.; Krishna K.U. (2011). Effect of environmental condition, method and time of grafting on graft success in two varieties of jackfruit. Proceedings of ISMF & MP Kalyani.

Heiner, I.J.; Smith, C.D. (1990a). Soils of the South Johnstone research station. Queensland Department of Primary Industries.

Heiner, I.J.; Smith, C.D. (1990b) Soils of the Utchee Creek substation. Queensland Department of Primary Industries.

Islam, M.; Haque, M.; Hossain, M. (2003). Effect of age of rootstock and time of grafting on success of epicotyle grafting in Jackfruit (*Artocarpus heterophyllus* L.). Asian Journal of Plant Science. 2: 1047-1051

Islam, M.S.; Farooque, A.M.; Rahim, M.A.; Haque, T. (2004). Effect of age of rootstock and scion defoliation on epicotyl grafting in jackfruit. Bangladesh J. of Crop Science 13(15): 89-93.

Jupa, R.; Mészáros, M.; Plavcová, L. (2021). Linking wood anatomy with growth vigour and susceptibility to alternate bearing in composite apple and pear trees. Plant Biology, 23: 172-183.

Khatamian, H.; Hilton, R.J. (1977). The Relationship between shoot growth and area of trunk Cross-section in several woody plant species. HortScience 12: 255-257.

Khatun, M.J.M; Rahim, M.A.; Islam M.S.; Alam, K.H. (2006). Propagation of jackfruit by grafting as influenced by time and method of grafting and age of scion. J Bangladesh So. Agric. Sci. Technol. 3(1, 2): 209- 212.

Konhar, T.; Murmu, S.; Maharan, T. (1990). A study on the budding methods of propagation of jackfruit. Orissa Journal of Agricultural Research, 3(2): 115-119.

Mannan, M.A.; Islam, M.M.; Khan, Saku (2006). Effects of methods of grafting and age of rootstock on propagation of off-season germplasms of jackfruit. Khulna University Studies. 7(2): 77-82.

Medina Tiznado, M. de L. A.; Luna Esquivel, G.; Cambero Campos, O. J.; Ramírez Guerrero, L. G.; Rios Velasco, C. (2018) *Lasiodiplodia theobromae*, the causal agent of soft rot of fruits of *Artocarpus heterophyllus* in Nayarit, Mexico. Revista Brasileira de Fruticultura. 40 (5).

Mukherjee, S.K.; Chatterjee, B.K (1979). Effects of forcing, etiolation and Indole Butyric Acid on rooting of cuttings of Artocarpus heterophyllus Lam. Scientia Horticulturae 10: 295-300.

Murtha, G.G. (1975). Soils and land use on the northern section of the Townsville coastal plain, north Queensland. Soils and Land Use Series, no. 55. CSIRO Australia, Division of Soils.

Nesme, T.; Plenet, D.; Hucbourg, B.; Fandos, G.; Lauri, P.E. (2005). A set of vegetative morphological variables to objectively estimate apple (Malus× domestica) tree orchard vigour. Scientia horticulturae, 106: 76-90.

Ni, H.F.; Chen, R.S.; Chang, S.F.; Yang, H. (2008). First Report of Lasiodiplodia Fruit Rot of Jackfruit in Taiwan. Plant Disease. 92: 1137-1137.

Rashid, A.Q.M.; Meah, M.B.; Sultana, A. (2015). Seed Borne Fungal Diseases of Fruits in Mymensingh District. Journal of Environmental Science and Natural Resources. 8: 153.

Retief, E.; McLeod, A.; Fourie, P.H. (2006). Potential inoculum sources of *Phaeomoniella chlamydospora* in South African grapevine nurseries. European Journal of Plant Pathology 115: 331- 339.

Singh, A.K.; Singh G.N. (2004). Effect of IBA and NAA on rooting of air layers of jackfruit (*Artocarpus heterophyllus* Lam). Scientific Horticulture 9: 41-46.

Slippers, B.; Roux, J.; Begoude, D.; Mehl, J.; Van der Linde, J.; Pavlic-Zupanc, D.; Walt, F.; Maleme, H.; Hinze, B.; Marais, G.; Wingfield, B.; Wingfield, M. (2010). Diverse communities of the Botryosphaeriaceae infect native trees in Southern Africa. South African Journal of Botany. 76(2): 415.

Soepadmo, E. (1991). Artocarpus heterophyllus Lamk. In E.W.M. Verheij & R.E. Coronel (Eds.), Plant Resources of Southeast Asia No. 2: Edible Fruits and Nuts (pp. 86-91). Wageningen, Netherlands: Plant Resources of South-East Asia.

Tomar Y.K. (2011). Effect of various concentrations of bio-regulators and time of air layering on the multiplication of jackfruit (Artocarpus heterophyllus Lam.) Int. J. of Current Research 3(6): 316- 318.

Trakunyingcharoen, T.; Lombard, L.; Groenewald, J.Z.; Cheewangkoon, R.; To-anun, C.; Crous, P. (2014). Caulicolous Botryosphaeriales from Thailand. Persoonia - Molecular Phylogeny and Evolution of Fungi. 34: 87-99.

Tri, M.V.; Nguyen V.H.; Nguyen M.C.; Antonella P.; Roberto F.; Alessandro D.; Leonardo S, et al. (2015) Decline of Jackfruit (Artocarpus Heterophyllus) Incited by Phytophthora Palmivora in Vietnam. Phytopathologia Mediterranea. 54(2): 275–80.

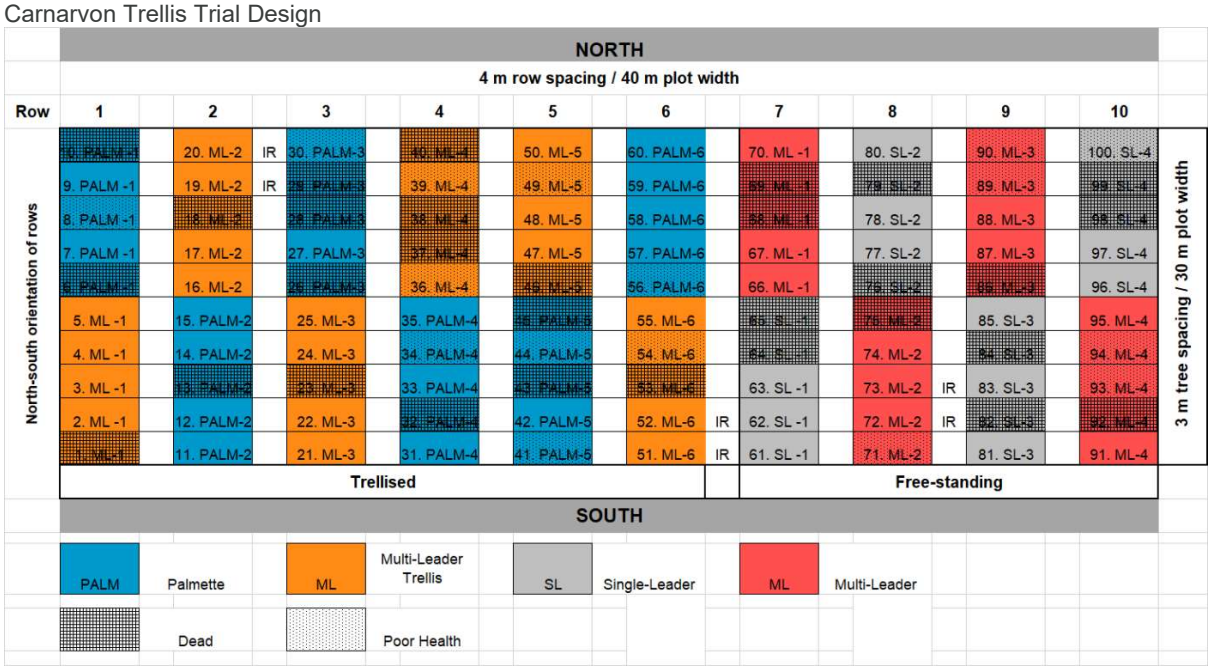
Waite, H.; Gramaje, D.; Weckert, M.; Torley, P.; Hardie, W. (2013). Soaking grapevine cuttings in water: A potential source of cross contamination by micro-organisms. Phytopathologia Mediterranea. 52(2): 359-368.

Whiteman, S.A.; Jaspers, M.V.; Stewart, A.; Ridgway, H.J. (2004). Identification of potential sources of Phaeomoniella chlamydospora in the grapevine propagation process. Phytopathologia Mediterranea 43(1): 152–153.

Appendices

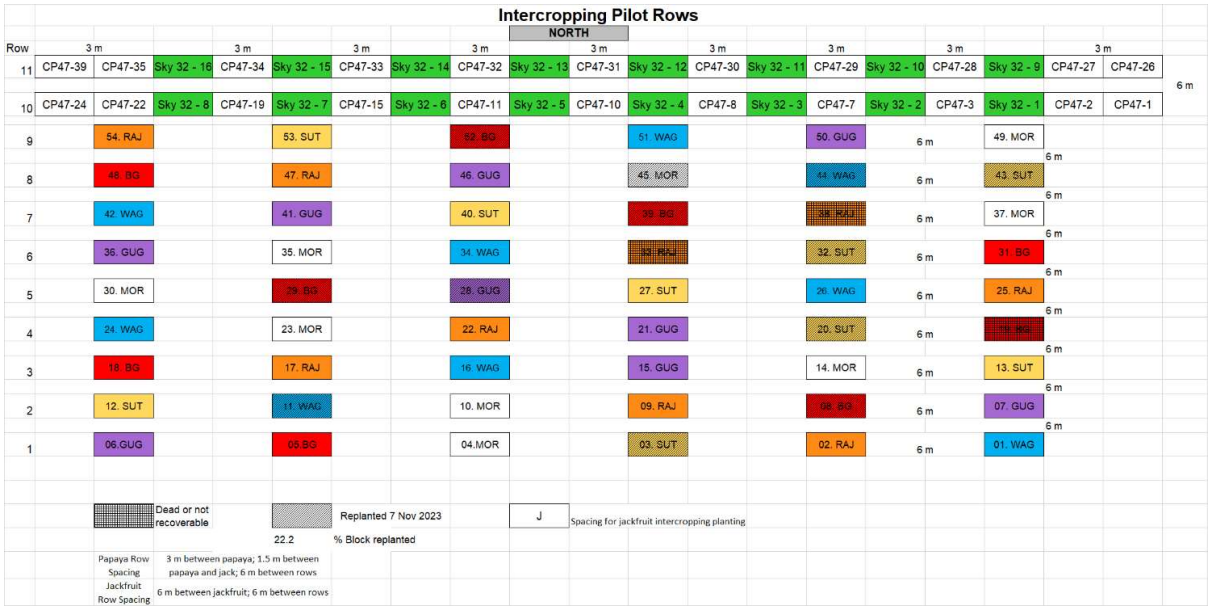
Appendix A

Carnarvon Trellis Trial Design



Appendix B

Carnarvon Jackfruit Variety Trial design and variety codes. Note: codes are 2-3 letters based on variety or growers name if variety is unknown.



Variety	Code
Black Gold	BG
Unknown	GUG
Unknown	MOR
Rajang	RAJ
Unknown	SUT
Unknown	WAG

Appendix C

Kununurra Trellis Trial map of varieties

	Row 8	Row 7	Row 6	Row 5	Row 4	Row 3	Row 2	Row 1	
Guard	Trellis	Free	Trellis	Trellis	Free	Trellis	Trellis	Free	Guard
CP47 grafted	Rajang	Rajang	Rajang	Rajang	Rajang	Rajang	Rajang	Rajang	Rajang
CP47 grafted	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Rajang
CP47 grafted	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Rajang
Thy1 grafted	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Rajang
CP190 grafted	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Rajang
CP190 grafted	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Rajang
Rajang	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Galaxy	Rajang
Rajang	Rajang	Rajang	Rajang	Rajang	Rajang	Rajang	Rajang	Rajang	Rajang

Appendix D

Kununurra Trellis Trial design

Freestanding - F									
Trellised Palmette (T-P)									
Trellised Multi-Leader (T-ML)									
Variety – Galaxy seedling									
5 reps									
No. trial trees	48								
No. guard trees	32								
Total no. trees	**80**								
4m x 4.5m									
Length	32								
Width	40								
Guard	Guard	Guard	Guard	Guard	Guard	Guard	Guard	Guard	Guard
Guard	T-ML	F	T-P	T-ML	F	T-ML	T-P	F	Guard
Guard	T-ML	F	T-P	T-ML	F	T-ML	T-P	F	Guard
Guard	T-ML	F	T-P	T-ML	F	T-ML	T-P	F	Guard
Guard	T-P	F	T-ML	T-P	F	T-P	T-ML	F	Guard
Guard	T-P	F	T-ML	T-P	F	T-P	T-ML	F	Guard
Guard	T-P	F	T-ML	T-P	F	T-P	T-ML	F	Guard
Guard	Guard	Guard	Guard	Guard	Guard	Guard	Guard	Guard	Guard

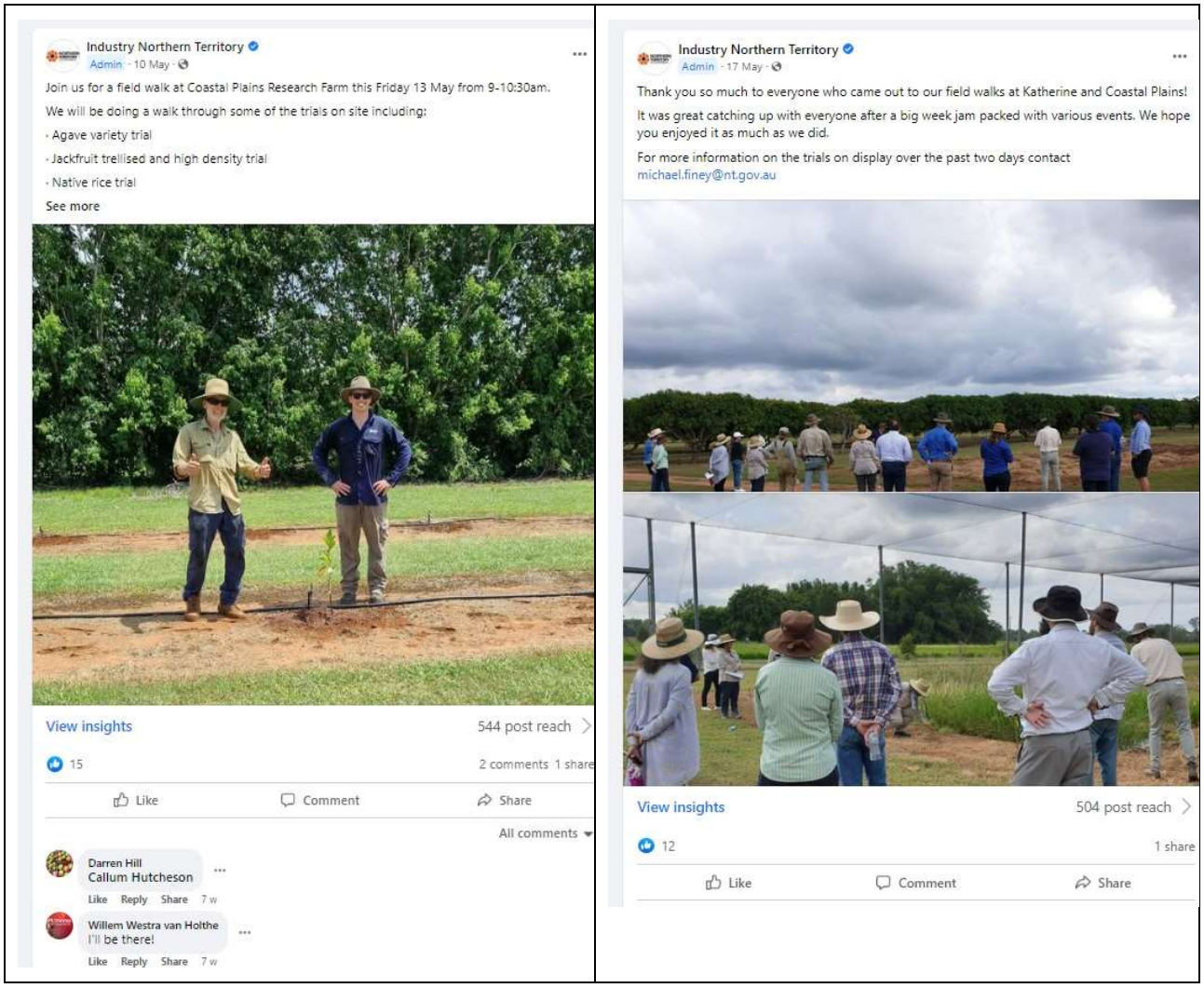
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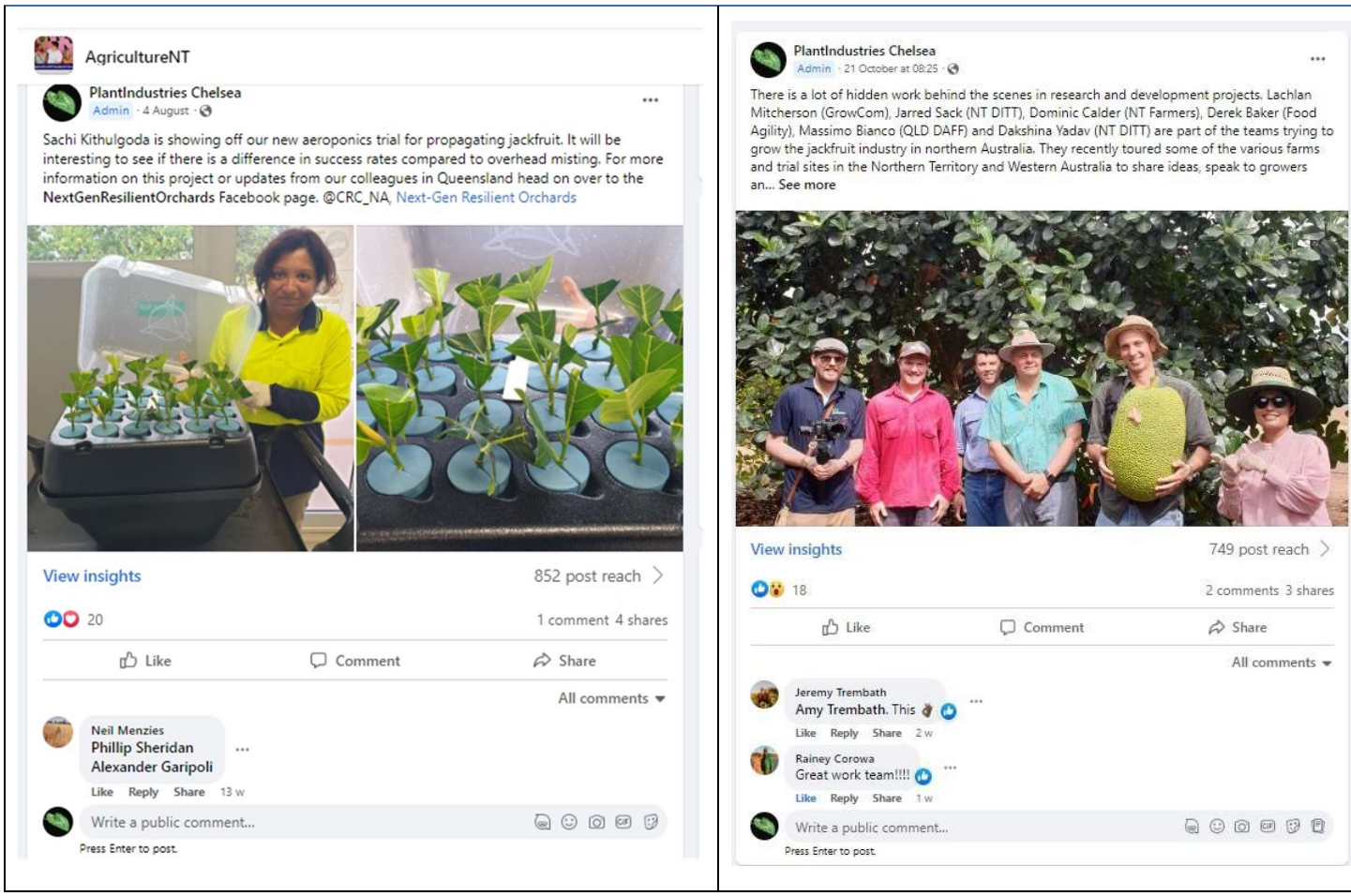
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Appendix E

Extension and engagement



Social media advertising field day 10/5/2022 (544 post reach and social media thank you for coming to field day 17/5/2022 (504 post reach).



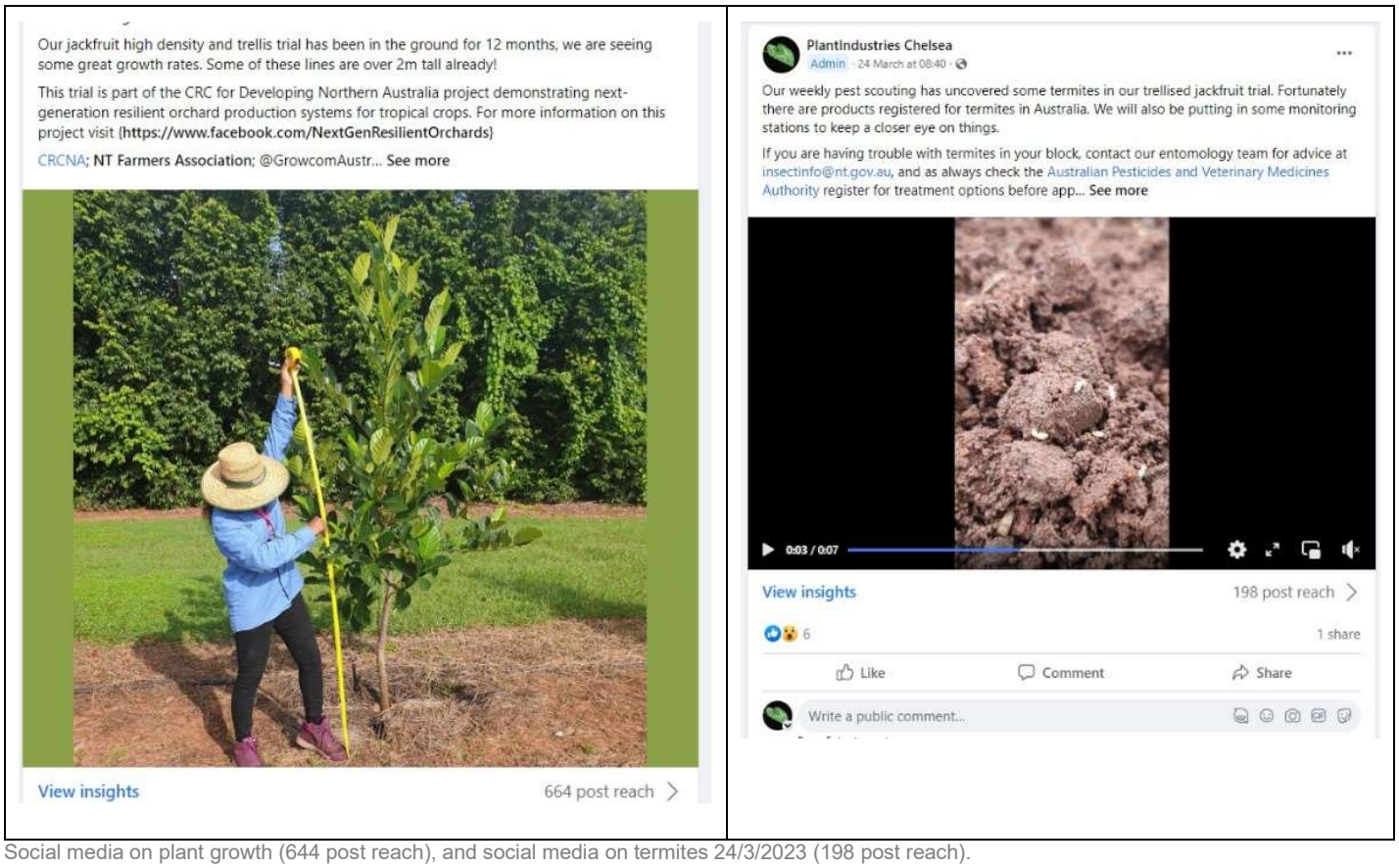
Social media on aeroponics 4/8/2022 (852 post reach) and generic social media post on jackfruit 21/10/2022 (749 post reach).



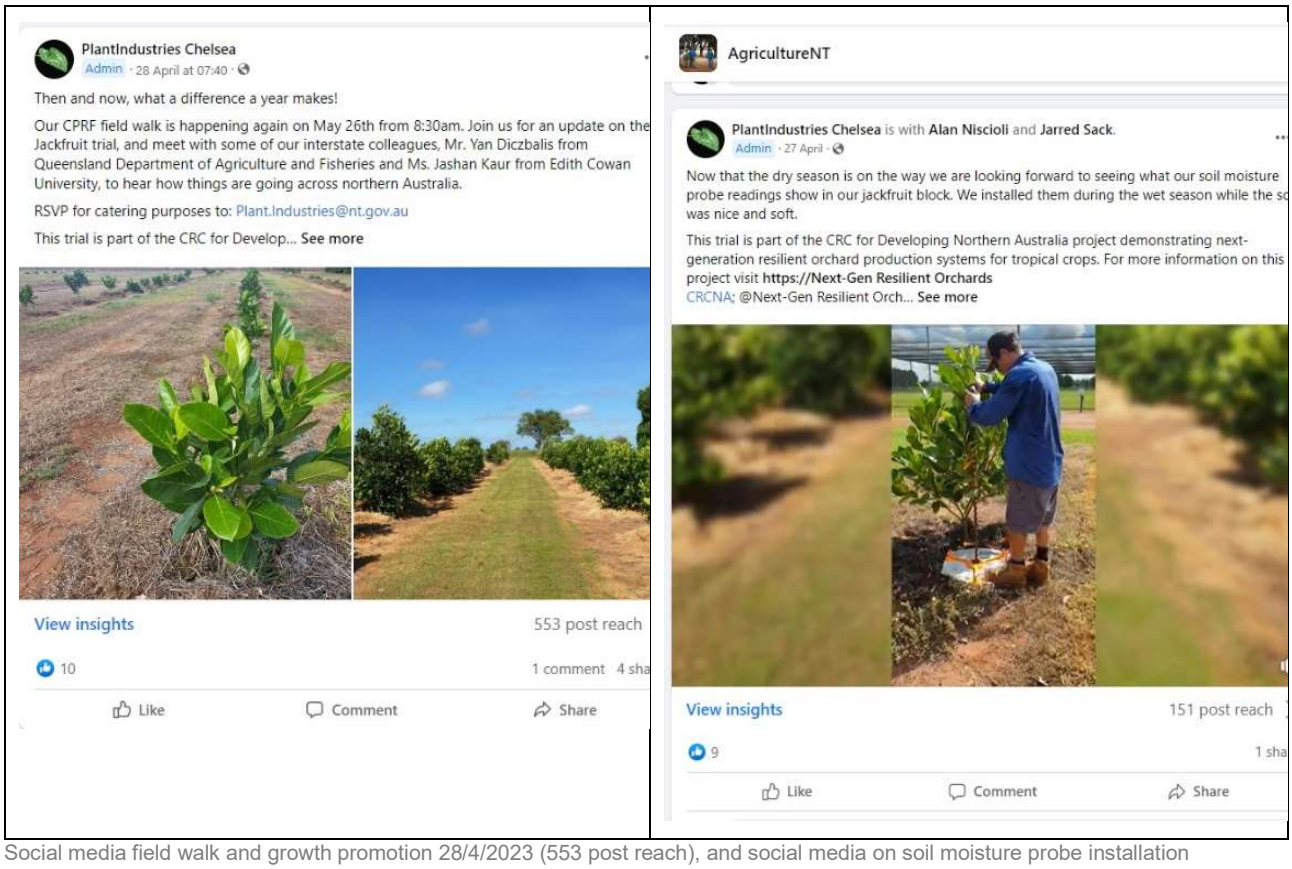




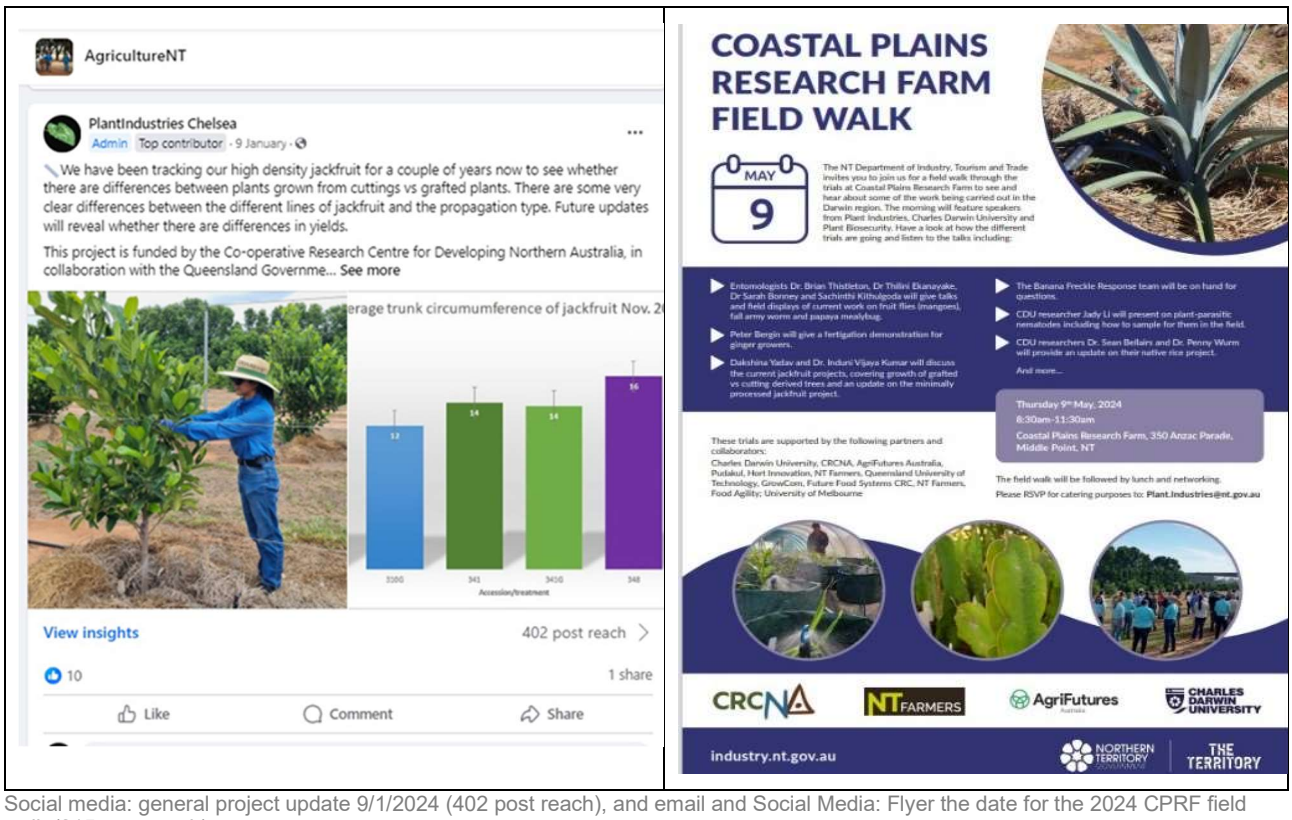
CPRF field walk 13/5/2022 (top), CPRF field walk 26/5/2023 (middle), CPRF Field walk 9/5/2024.



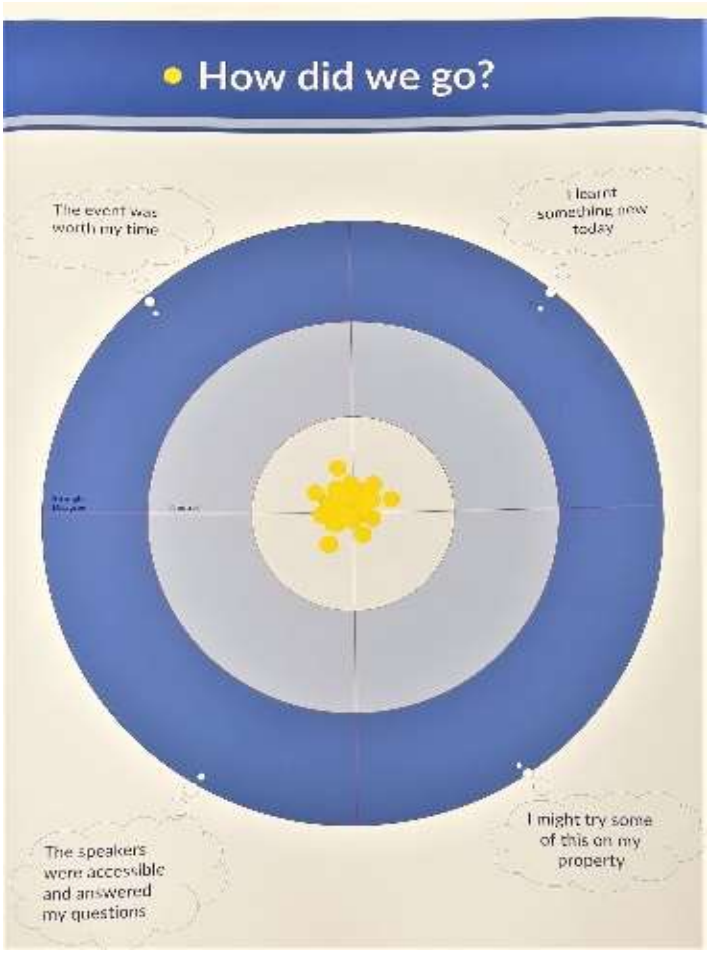
Social media on plant growth (644 post reach), and social media on termites 24/3/2023 (198 post reach).



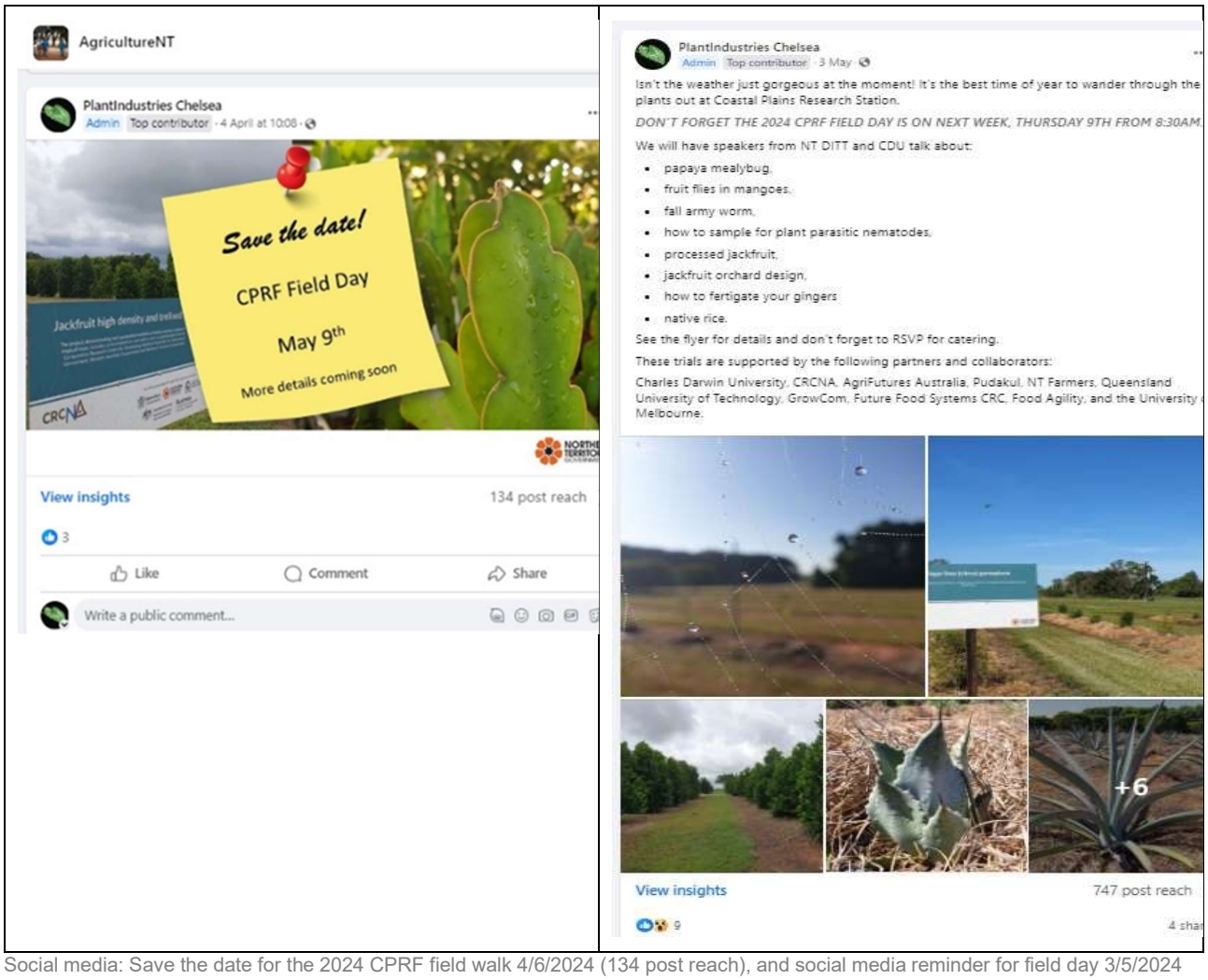
Social media field walk and growth promotion 28/4/2023 (553 post reach), and social media on soil moisture probe installation 27/4/2024 (151 post reach).



Social media: general project update 9/1/2024 (402 post reach), and email and Social Media: Flyer the date for the 2024 CPRF field walk (315 post reach).



Feedback from field day.



Social media: Save the date for the 2024 CPRF field walk 4/6/2024 (134 post reach), and social media reminder for field day 3/5/2024 (747 post reach).