Final report

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Managing mangoes for future climates

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Related documentation:

This project report is drawn from the University PhD thesis of Marcelo Amaral, whose living allowance scholarship was funded by this project. See https://acquire.cqu.edu.au/

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Public summary

Mango grower concerns about managing mangoes in a changing (warming) climate led to a public call for relevant research, with a secondary emphasis on training of a human resource relevant to the mango industry. A three-year project was contracted on 16 March 2023, with funding primarily supporting a three-year postgraduate living allowance scholarship, augmented by a CQUniversity fee scholarship and operating support. Marcelo Amaral commenced PhD candidature through CQUniversity on 24 March 2023, and submitted a thesis on 13 April 2026, under supervision of Prof Kerry Walsh (CQU), Cameron McConchie (as CQU Adjunct) and Geoff Dickinson (Qld DPI).

Project activities were based on commercial orchards, addressing four topics: (i) temperature requirements for floral initiation; (ii) chemical manipulation of trees to achieve floral initiation; (iii) growing degree day (GDD) requirements for floral initiation and fruit development; and (iv) assessment of harvest maturity.

Field trials were undertaken to ascertain temperature requirements for induction of flowering, and to recommend a chemical (paclobutrazol, ethephon, K_2SO_4) treatment package for manipulation of flowering time. These trials were undertaken in Darwin area NT, FNQ and CQ, on Calypso and HoneyGold trees in the 2024-25 season, and additionally in Kununurra in the 2025-26 season. Field trials to establish growing degree day (GDD) requirements for fruit development were run in the 2023-24, 2024-25 and 2025-26 seasons, involving KP, R2E2, Calypso, HoneyGold, NMBP and Keitt cultivars at multiple sites in Darwin area NT, FNQ and CQ.

A key feature of the project was grower engagement, with involvement in trial implementation and data collection, resulting in a number of growers adopting elements of the work into commercial practice. Oral presentations on the work were presented in AMIA NT and WA roadshows, and at the 2025 International Mango Symposium. Full documentation is available in the CQUni PhD thesis of Marcelo Amaral and will be published in referred journals.

Technical summary

The aim of this project was to improve the management of flowering, harvest timing, and maturity assessment in Australian mango (*Mangifera indica* L.) production. A review of the literature on mango flowering physiology and management options highlighted the interacting roles of temperature, water status, carbohydrate reserves, canopy condition, and plant growth regulators in floral induction. Four sets of experimental activity were then undertaken.

First, growing degree day targets for fruit development from flowering to minimum and maximum harvest maturity were validated for ‘B74’, ‘Honey Gold’, ‘Keitt’ and ‘Kensington Pride’ using data from 86 populations across 37 site-season combinations, and new targets were established for ‘R2E2’, ‘1243’, ‘Nam Dok Mai’, ‘1201’ and ‘4069’. A common thermal-time model using Tb = 12 °C and TB = 32 °C was recommended, and the harvest window was defined using flesh colour, SSC:TA, firmness and ripening time.

Second, the temperature conditions required for floral induction after tip pruning were quantified using data collected across three seasons, eight orchard sites, and 4,530 tagged terminals, with about five pruning dates per site. The best predictor of floral development was hours below a ‘threshold temperature’ (x) during bud development, tempered by warm interruptions. Region had a stronger influence on fitted x values than season. An x of 21.5 °C was established for ‘B74’ in Darwin and 15.0 °C in Far North Queensland, and 18.3 °C for ‘Honey Gold’ in Darwin and 15.0 °C in Bungundarra, with flowering associated with 120 to 130 h below x.

Third, chemical strategies to advance or delay flowering were evaluated across five production regions over three seasons. For advancement, PBZ-based programs were most effective when PBZ was applied at the final major vegetative flush, with PBZ + K_2SO_4 + KNO_3 generally the strongest treatment and PBZ + KNO_3 the best simplified option. In Darwin, the PBZ + K_2SO_4 + KNO_3 program increased flowering in ‘Honey Gold’ from 0.52 to 0.88 of terminals, increased yield from 28.7 to 87.0 fruit tree^{-1}, and advanced time to 50% flowering by 42 d. Similar nitrate-based PBZ programs also improved flowering, synchrony and yield in Darwin ‘B74’, advancing flowering by about two weeks.

Fourth, an extended colour-card series was recommended for assessing flesh colour, with minimum flesh-colour targets of 7 for ‘Nam Dok Mai’, ‘B74’, and ‘KP’; 9 for ‘1243’ and ‘Honey Gold’; 11 for ‘1201’ and ‘R2E2’; and 13 for ‘4069’ and ‘Keitt’. Pantone Plastic Standard Chips 461 C, 600 C, 7403 C, and 127 C were recommended, based on ΔEab measurements, as robust field aids for flesh colour assessment.

Keywords

bud fate, chill accumulation, forecast, harvest window, heat units, flowering physiology, PGRs, prediction, reproductive timing, reproductive transition, terminal readiness, temperature response, thermal time, synchrony

Introduction

This project was undertaken to develop science-based tools to support mango growers in managing flowering, through improved understanding of cool-temperature requirements for floral induction and the use of chemical manipulation, as well as harvest timing and maturity assessment, under current and future temperature regimes, with emphasis on cultivars grown in Australia. The overall aim was to generate practical recommendations that improve crop scheduling, help position harvest in better market windows, and strengthen resilience to climate variability and warmer conditions. A key objective was to move away from fixed calendar timing and towards temperature-based approaches that can be adjusted for cultivar, region, and season. The work was intended to support decision-making under variable and warming conditions, with improved understanding of cultivar differences relevant to future cultivar selection and breeding for climate resilience.

These aims were addressed through research in four interconnected areas:

(i) Improvement of understanding of the cool-temperature exposure required to trigger floral induction in the major Australian cultivars, in context of shoot age, vegetative condition, and other factors influencing floral responsiveness

(ii) Develop management practices to manipulate flowering involving chemical packages and management treatments to advance or delay flowering in Australian production systems; and linking flowering management to harvest-window planning.

(iii) Evaluating the use of temperature monitoring, thermal-time modelling, and forecasting approaches to improve prediction of fruit development and harvest timing in Australian mango production system, with recommendation of cultivar-specific harvest windows.

(iv) Development of practical indicators of fruit harvest maturity relevant to Australian value chains.

A secondary objective of the project was the development of a human resource relevant to the mango industry. This was approached through a PhD candidature based on on-farm field trials and grower involvement, involving a candidate who had a background of working on mango farms and had undertaken a MSc involving mango production, i.e., had a solid foundation, and expressed interest in developing a career around mango production.

This Final Report is drawn from the resulting PhD thesis (Appendix D).

Methodology

Literature Review

A literature review was based on a structured search of scientific literature, supported by citation tracking and selected industry and technical sources. Peer-reviewed publications were identified primarily through Scopus using the search string (“mango” OR “*Mangifera indica*”) AND “flowering” AND “manipulation”, with the search focused on publications from 1990 to 2025. The initial search returned 102 records. These were screened for relevance based on title and abstract, resulting in 54 papers being retained for closer consideration. A further 21 sources were identified through backward and forward citation tracking of key papers, including some earlier references published before 1990 where they remained relevant to the development of the topic. The review was also shaped by broader discussion with commercial mango growers and mango extension personnel in Australia and Brazil, particularly in understanding the practical development of mango flowering manipulation in those industries. These discussions helped frame the review and identify relevant themes, but the chapter itself was based on published and citable sources.

Temperature requirement for floral induction

Temperature requirements for floral induction were investigated over three seasons in tip-pruning trials involving five cultivars across eight orchard sites, with and without paclobutrazol (PBZ). Trees were pruned at different times so that developing buds experienced thermal conditions before, within and beyond the inductive cool period.

The experimental unit was an individual tree. On each pruning date, all terminals on a set of trees were tip pruned, with a different set of trees used on each date. Pruning dates were scheduled at approximately fortnightly to monthly intervals spanning the expected induction period for each location, i.e., five or six pruning dates per location. An unpruned control

(no additional tip pruning beyond routine orchard operations) was included at each site. Ten terminals on each tree were tagged, and monitored weekly for developmental fate, with measurement of the length of the vegetative or reproductive growth. Treatments were arranged in a randomized complete block design, with six replicate trees per treatment, e.g., a trial in which pruning occurred at 6 dates involved 36 pruned trees plus 6 control trees (42 trees). Thus, at this site, 4,530 tagged terminals were monitored for reproductive expression.

At two sites PBZ was included as a factorial treatment with individual trees as experimental units. Pruning-date treatments randomized in complete blocks of six replicate trees, producing matched PBZ versus control comparisons within the same site-season.

At each site, temperature was remotely logged at 15-minute intervals using a SensorHost (Rockhampton, Australia) system mounted 1.2 m above mulched or grassed ground.

Working in R, including the package 'chillR', the thermal metrics of a fitted threshold temperature (x) and 'hours below x' were evaluated in context of both first and second growth units (growth following pruning). The extent of variation in x with growing region, cultivar and season was evaluated. Thresholds were pooled across seasons within repeated site × cultivar backgrounds to test whether a common operational x could be recommended across seasons for the same production context.

Chemical manipulation of flowering

Several programs for chemical manipulation of mango flowering were evaluated in field trials in three seasons and in five Australian production regions to improve flowering synchrony and reposition harvest timing. The work examined: (1) timing of paclobutrazol (PBZ) relative to pruning, (2) PBZ-based programs for advancing flowering, and (3) programs for delaying flowering. From Exercise 1, it was concluded that PBZ should be timed to the final major vegetative flush rather than to a fixed early post-harvest deadline, and this methodology was implemented in Exercises 2 and 3.

Trials were designed to separate the effects of individual chemicals from their combined effects on vegetative flushing control, terminal maturity, floral induction and subsequent yield, and then to evaluate operational programs in varied growing conditions. Two experimental designs were used depending on site logistics and grower equipment. Where sites were researcher accessible and backpack spraying was feasible, the individual tree was the experimental unit, with six replicates arranged in a randomized block design (e.g., five treatments × six replicates = 30 trees per site), including an untreated control. Treated trees were separated from other treatments by at least one untreated guard tree to minimize cross-contamination due to spray drift. For grower maintained sites, treatments were imposed using commercial tractor based spray equipment, with a tree row as the treatment unit.

Nine treatments (T1 to T9) were evaluated for early-flowering induction (Fig. 1). Treatments were defined as: T1 = untreated control, T2 = PBZ, T3 = PBZ + KNO_3, T4 = PBZ + K_2SO_4 + KNO_3, T5 = PBZ + ethephon + KNO_3, T6 = PBZ + K_2SO_4 + ethephon + KNO_3, T7 = K_2SO_4 + ethephon + KNO_3 (no PBZ), T8 = K_2SO_4 + KNO_3 (no PBZ/ethephon), and T9 (emergency program) = PBZ (spray) + Ethephon, KNO_3. PBZ was delivered via soil application (drench/fertigation depending on site logistics), whereas ethephon and KNO_3 were applied as foliar sprays.

Thermal time for fruit development

The thermal time (also known as heat units or Growing Degree Days, GDD) required for fruit development was established through trials conducted in the 2023, 2024 and 2025 seasons on commercial farms and research stations across Queensland (QLD) and the Northern Territory (NT), Australia, spanning latitudes from approximately 12° to 23° S. The study involved activity in 86 'populations' of 11 cultivars in 37 unique locations-seasons, with each site usually involving several cultivars (Table 1). For each population, i.e., season-site-cultivar, fruit were harvested at several dates, referred to as 'cohorts' of fruit. The cultivars included both commercially established cultivars and advanced breeding selections. Sites were selected to capture a wide range of tropical and subtropical temperature regimes characteristic of Australian mango production regions. Time-to-ripen assessments were made on some population cohorts.

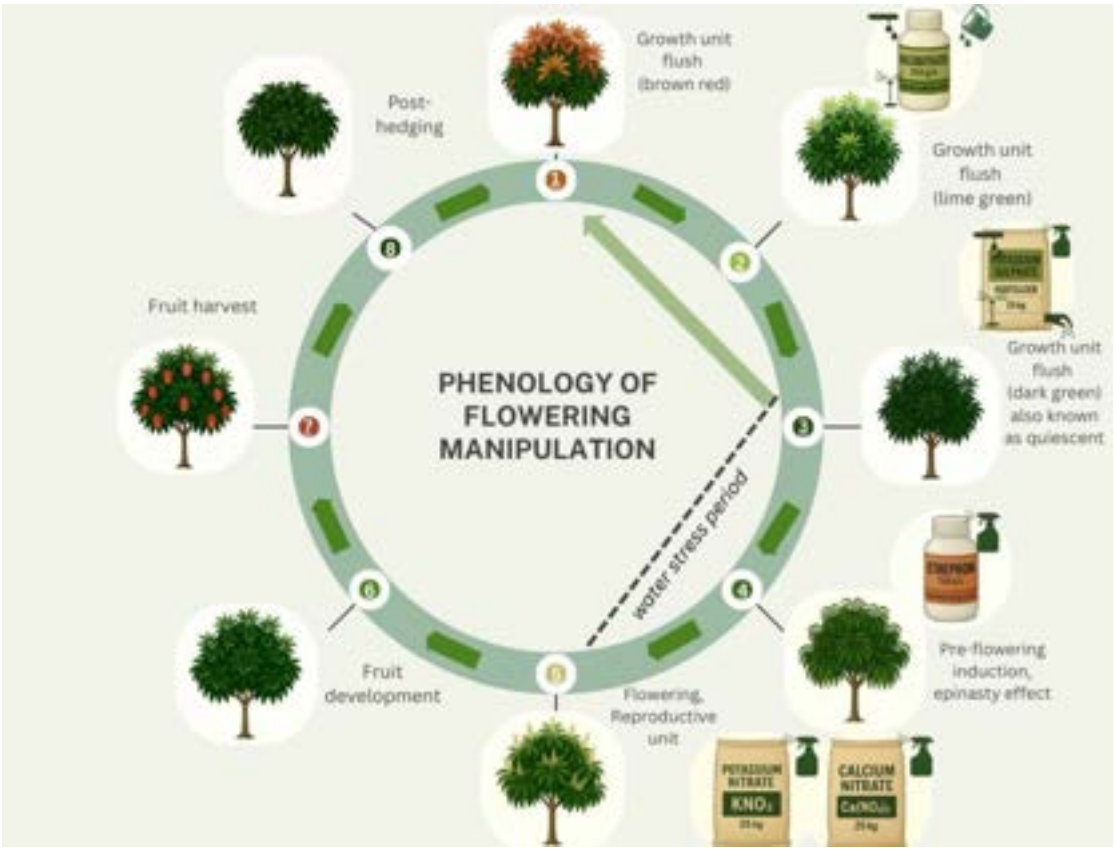


Figure 1. Manipulation sequence used to induce mango flowering. (a) Paclobutrazol applied by soil drench or fertigation; (b) potassium sulphate applied as a foliar spray, soil fertilizer or by fertigation; (c) mild water deficit during shoot maturation; (d) ethephon applied as a foliar spray where included in the program; (e) potassium nitrate or calcium nitrate applied to stimulate bud-break; and (f) return to irrigation and/or renewed canopy activity, which may lead either to floral emergence or, in some cases, to a further vegetative flush before flowering. The arrow within the cycle indicates that an additional vegetative flush may occur before the next induction sequence.

Table 1. Locations, production regions, climate zones, seasons, and cultivars included in growing degree day assessment trials. Locations were in Queensland (QLD), Western Australia (WA), and the Northern Territory (NT), Australia.

Cultivar(s)	Season(s)	Location	Region	Latitude (°S)	Longitude (°E)
'B74', 'KP', 'Nam Dok Mai', 'Agam'	2023–2025	Acacia Hills, NT	Top End	−12.7541	131.1677
'Honey Gold'	2023–2024	Lambells Lagoon, NT	Top End	−12.5480	131.2593
'R2E2'	2023	Lambells Lagoon, NT	Top End	−12.6071	131.2258
'KP'	2023	Fly Creek, NT	Top End	−12.7914	131.0969
'KP', '1243'	2023–2024	Lake Bennett, NT	Top End	−12.9640	131.1712
'1243', '1201', '4069'	2023–2025	Katherine, NT	Katherine region	−14.4652	132.3132
'Lady Jane', 'R2E2'	2023–2025	Katherine, NT	Katherine region	−14.5414	132.4696
'R2E2', '1243', '4069'	2025	Katherine, NT	Katherine region	−14.6153	132.2052
'1243', '1201'	2023	Kununurra, WA	Ord River	−15.6517	128.7094
'1243', 'R2E2', 'Nam Dok Mai'	2025	Kununurra, WA	Ord River	−15.7210	128.6932
'R2E2'	2025	Bowen, QLD	Burdekin	−20.0190	148.1855

Cultivar(s)	Season(s)	Location	Region	Latitude (°S)	Longitude (°E)
'1243', 'R2E2'	2025	Gumlu, QLD	Burdekin	−19.8641	147.7052
'1243', '1201', 'R2E2'	2025	Brandon, QLD	Burdekin	−19.5954	147.3131
'B74', 'KP'	2023–2024	Dimbulah, QLD	Atherton Tablelands	−17.1260	144.9881
'Honey Gold'	2023	Dimbulah, QLD	Atherton Tablelands	−17.1543	145.0916
'B74'	2023	Dimbulah, QLD	Atherton Tablelands	−17.1084	145.0874
'1243', '4069', 'KP', 'R2E2'	2023–2024	Mutchilba, QLD	Atherton	−17.1328	145.2970
'Keitt'	2023	Mutchilba, QLD	Atherton Tablelands	−17.1709	145.1944
'Keitt', '1243', 'B74', 'R2E2', '1201'	2023–2025	Walkamin, QLD	Atherton Tablelands	−17.1381	145.4283
'KP', 'Nam Dok Mai', 'R2E2', 'Keitt', 'HG'	2023–2025	Bungundarra, QLD	Central Queensland	−23.0219	150.6376
'KP', 'Nam Dok Mai', 'R2E2', 'Honey Gold'	2023–2025	Rockhampton, QLD	Central Queensland	−23.3220	150.5161

For each site, season and cultivar, populations of approximately 200 panicles were tagged at flowering, with subsequent monitoring of fruit development and maturity. Coloured biodegradable flagging tape (Forestry Tools Australia, Sydney, NSW, Australia) was used. This tape remained intact for the duration of a season, and although some colour fading occurred, discrimination among tagging panicle events remained acceptable.

The optimal Tb and TB for each cultivar was estimated using a coefficient of variation (CV) minimization approach. For Tb optimization, GDD accumulation was calculated across a range of candidate Tb values from 1 °C to 20 °C in 0.5 °C increments, while TB was held constant. Following Tb optimization, the upper threshold temperature (TB) was optimized by recalculating GDD accumulation using candidate TB values ranging from 25 °C to 37 °C in 0.5 °C increments, while holding Tb constant.

Postharvest ripening assessments were conducted on a subset of harvest fruit spanning a range of GDD values for each cultivar. For each harvest population cohort (site × cultivar × season × harvest date), approximately 50% of the harvested fruit were allocated to the ripening assessment, with a typical batch size of about 10 fruit. Fruit were held at ambient laboratory conditions of 20 °C, i.e., within the recommended temperature range of 18–20 °C for mango ripening. Ripening progress was monitored at two-day intervals by tactile assessment using whole-hand pressure.

Harvest maturity assessment

The flesh colour associated with minimum harvest maturity was documented for the major cultivars in Australian production, extending previously available advice, based on a dataset involving populations of 9 cultivars from 11 locations over 7 seasons, with fruit of known GDD from flowering harvested at intervals for assessment of internal attributes. Variation in the colour of printed colour cards in use by industry to assist flesh colour assessment was documented using a CR400 colorimeter (Minolta, Japan), both between printing run and with age. In addition, plastic color cards (Pantone, USA) were evaluated.

Results and discussion

Temperature requirement for floral induction

Mango flowering is best understood as a response shaped by both terminal condition and temperature. Trees do not flower because of one product or one calendar date. They flower when shoots have reached a suitable stage of maturity and then experience conditions that favour reproductive development over continued vegetative growth. Because a combination of factors are required, flowering is often irregular in commercial orchards. A canopy can contain terminals of different ages, under different source-sink conditions, and these terminals enter the inductive period at different states of readiness. The practical challenge is therefore not simply to apply a treatment, but to bring the canopy into a condition in which it can respond well when inductive conditions occur. Given correct physiological condition, cool-temperatures can trigger flowering. Knowledge of the temperatures required for induction provides a tool: the better to plan timing of chemical programs to aid induction of flowering.

Cool temperature conditions associated with flowering (Fig. 2) were characterized by region and cultivar in terms of time (hours) below a threshold temperature x. Values of 21.5 °C for 'B74' in Darwin, 15.0 °C for 'B74' in Far North Queensland, 18.3 °C for 'Honey Gold' in Darwin and 15.0 °C for 'Honey Gold' in Bungundarra were recommended, with flowering commonly associated with about 120 to 130 h below x. 'R2E2' and 'KP' appear capable of flowering under relatively warm conditions in the north, while '1243' appeared more affected by warm interruptions, but all three still need more data before firm operational thresholds can be recommended.

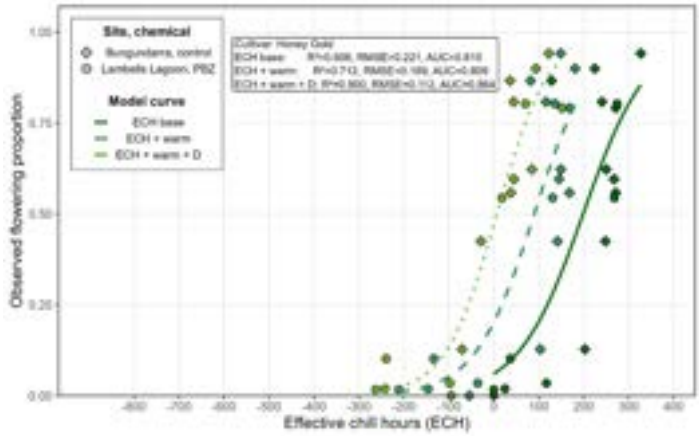


Figure 2. Observed flowering proportion plotted against effective chill hours (ECH) for 'Honey Gold' under three fitted models: ECH base, ECH + warm, and ECH + warm + D. Points represent cohort observations from populations defined by site × season × PBZ treatment; point shape identifies the site × chemical stratum. Lines show the fitted response curves for each model. Boxed text reports model performance statistics (R^2, RMSE and AUC).

The tip-pruning work showed that the inductive period after bud release can be described in terms of hours below a fitted threshold temperature, x, but warm interruptions, timing of cool exposure during early bud development, and flush maturity all influenced the outcome (Fig. 3). The identified thresholds should therefore be treated as regional operational guides rather than fixed cultivar constants. In general, 'Honey Gold' required cooler conditions and was more affected by warm interruption, which helps explain its less reliable flowering under warm tropical conditions. By contrast, 'B74' showed greater tolerance of warmer inductive conditions, consistent with its more stable behaviour across the tip-pruning and chemical-manipulation studies. These differences are important not only for current orchard management, but also for thinking about cultivar suitability under warmer future climates. This variation in heat tolerance should be considered in future selection/breeding programs.

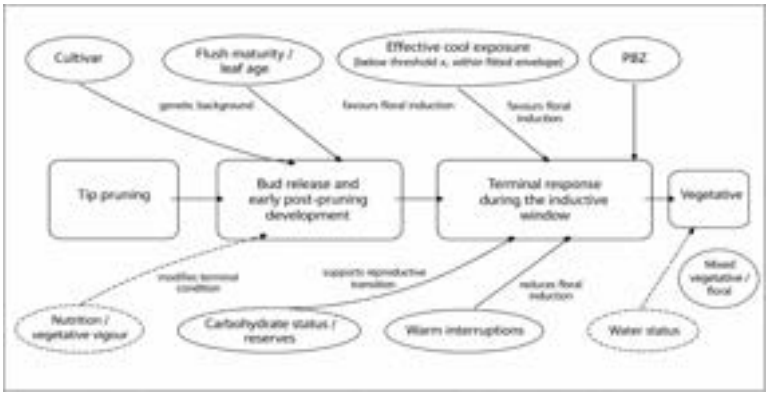


Figure 3. Conceptual framework linking tip pruning, terminal condition, and the post-pruning thermal environment during the early inductive window to final terminal fate.

Chemical manipulation of flowering

The chemical-manipulation work led to the same conclusion as the cool temperature study: PBZ, nitrate, potassium sulfate and ethephon did not act as simple on-off switches for flowering. Their effects depended on when they were applied, the condition of the canopy, and whether the seasonal environment was suitable for the intended response. The strongest and most consistent early-flowering responses came from programs that first improved terminal maturity and then used nitrate to trigger a more even bud break close to inductive conditions. Thus, PBZ was more effective when timed to the final major vegetative flush rather than to a fixed early post-harvest deadline. Note that this timing is contrary to the current Australian Pesticides and Veterinary Medicines Authority (APVMA) label permit and thus cannot be currently implemented. In Darwin 'Honey Gold', the strongest program substantially improved flowering, yield and earliness, and across the broader work it was clear that flowering or harvest timing could be shifted by about 2 to 3 weeks, when treatment timing and seasonal conditions aligned well.

For advancement of flowering in warm tropical systems, PBZ + K_2SO_4 + KNO_3 was the strongest overall program trialed, while PBZ + KNO_3 was the strongest simpler alternative. K_2SO_4 and KNO_3 are APVMA exempt active constituents as they are categorized as a common plant nutrient rather than a restricted chemical,

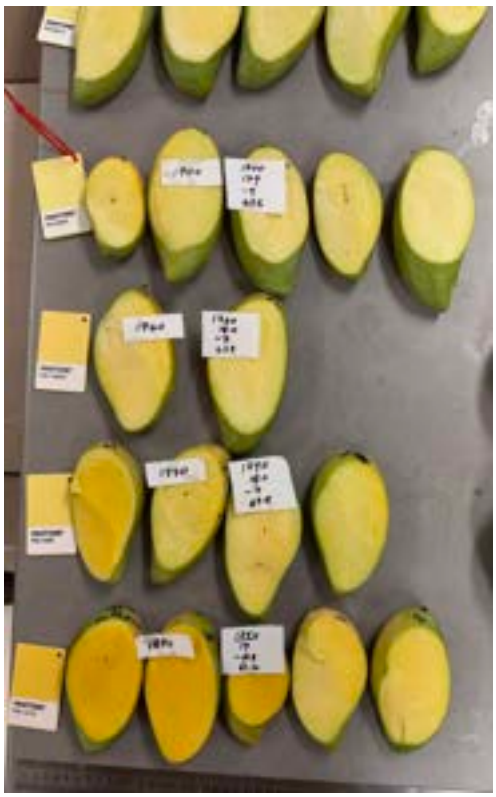
The broader lesson is that flowering in Australian mango can only be shifted within biological limits. It can be guided, concentrated and repositioned, but it cannot yet be forced to flower at will throughout the year as achieved in systems such as Petrolina, Brazil, with Embrapa's mango flowering induction programs. Delay programs were also possible, especially in subtropical environments, but they were less dependable than advancement programs. GA_3 showed some potential to maintain terminals in a vegetative state under inductive conditions and thereby delay progression, but this approach still requires more development before it can be recommended for commercial practice.

Thermal time for fruit development

Harvest forecasting is improved when fruit development is expressed in thermal time rather than in calendar days, calculated used a bounded GDD model with Tb = 12 °C and TB = 32 °C is recommended across cultivars and regions. An important extension of previous work was the definition of a harvest window, involving not only a minimum maturity (at minGDD) but also a maximum maturity (maxGDD) for each cultivar that delivered fruit with a postharvest shelf life suitable for the major Australian value chains. In this context, time to ripen proved useful as a practical maturity criterion, adding information that had not been well incorporated into earlier GDD work.

Recommended harvest windows are 1724–2017 GDD for 'B74', 1747–2083 for 'Honey Gold', 1606–1946 for 'Kensington Pride', 1531–1896 for 'Nam Dok Mai', and 1459–1743 for '1243'. Recommended minimum harvest maturity targets are 1509 GDD for 'R2E2', 2211 for 'Keitt', 1670 for '1201' and 1670 for '4069', but the upper boundary still needs better definition for 'R2E2', and both minimum and maximum targets for '1201' and '4069' require further validation.

Harvest maturity assessment



The maturity assessment work provided a foundation to the thermal time (GDD) recommendations. Australian growers already use flesh colour for assessment of harvest maturity, often with NIR-dry matter as a supporting tool. However, the existing colour card resources available for flesh colour assessment do not cover the colour range of all cultivars, and the printed cards fade with time and differ between print runs. Recommendations were made on flesh colour targets by cultivar, and for the use of field robust Pantone® polypropylene colour chips (Fig. 4). At <AUD50 per chip, these chips should see ready adoption by growers.

Figure 4. Pantone® polypropylene colour chips shown next to freshly cut cheeks of fruit of a range of maturities (GDD). Photo by author.

Conclusion

The terms 'early-', 'mid-', or 'late-' season cultivar are ambiguous. The same cultivar may be harvested relatively early in one region and much later in another, depending on time of flowering, thermal regime and the maturity standard being targeted. The manipulation of the harvest window therefore needs coordinated consideration of both flowering and fruit development.

Warmer and more variable conditions are likely to affect both flowering reliability and the rate of fruit development, which means that the cultivars, regions and management programs that perform well in the future may not be the same as those favored in the past. The Darwin region is likely to have fewer cool periods and cultivars that require stronger cool conditions such as 'Honey Gold' will be increasingly prone to seasons of poor flowering. CQ will likely still have inductive temps, but development time will be shortened, resulting in an earlier harvest.

Given cultivar differences in cool induction requirements for flowering and in the thermal time required for fruit development, there is potential to breed for these characters. Consider that the recently released cultivars from the Australian National Breeding Program were in development for 25 years. A breeding program commencing now might therefore not see material released to commercial use until 2050. If the release is in commercial use for 30 years, then consideration should be given to the expected climate of 2080 in the current breeding selection program.

Outputs

Table of Outputs.

Output	Description	Detail
PhD thesis	Full documentation of project work and associated literature	As of 15/05/26, thesis is under examination. Once finalized, the document will be publicly available at

	review	https://acquire.cqu.edu.au/
Industry and stakeholder communication	Oral presentations in Darwin, Katherine and Kununurra Direct grower discussion Interaction with NT DITT, Qld DAF and WA DPIRD (Kununurra) staff	at AMIA 2024, 25 and 26 'roadshows'and to Mango 'SIAP'. On-farm trials with grower engagement were undertaken in Darwin, Katherine, Kununurra, Mareeba, Bowen and Rockhampton growing regions. Physical support provided by NT DITT (Katherine accommodation and access to research station trees, and support of postharvest assessments), Qld DPI (starch analyses; access and monitoring of trial on Walkamin Research Station trees). An extension of this project forms part of a proposal submitted to Hort Innov Frontiers by Qld DPI.
Academic publication	Paper presented at Int Mango Symposium (May 2025)	Manuscript accepted by Acta Horticulturae
Support of/ interaction with QUT Tree Genomics program	Bud material of known provenance and physiological history collected and supplied to QUT.	Samples preserved in cold store. Analyses delayed due to delayed start of QUT candidate, with outcomes to fall outside the period of MG22000.

Outcomes

Table: Outcome summary.

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Practical knowledge	Industry awareness and practice change	Direct discussions with growers, presentation in AMIA events, grower engagement in hosting trials, growers using GDD recommendation on timing of harvest maturity and extending chemical manipulation recommendations	Discussion at Mango SIAP
Human resource development	PhD candidate Grower involvement and engagement	Thesis submitted and candidate continuing in mango industry Grower involvement in discussion and field trials	PhD thesis submitted to CQU; candidate purchased land in a mango production region and developing a 'mango career' (Fig. 5). Field trial results from multiple farms.

Availability of new knowledge for next phase project		An extension of this project forms part of a proposal submitted to Hort Innov Frontiers by Qld DPI	Proposal submitted to HI

Monitoring and evaluation

Table: Key Evaluation Questions

Key Evaluation Question	Project performance	Continuous improvement opportunities
Candidature progress	Thesis submitted (under examination as of 15/5/26)	Refereed journal articles to be written from thesis chapters.
Technical rigor as demonstrated by publication	Thesis submitted, one scientific journal paper accepted, one article for Mango Matters	Further scientific journal publications to be generated.
Industry awareness	Widespread industry awareness achieved through direct discussion with a wide selection of growers and on-farm trials - across three states, and presentation at multiple industry events.	Potential to expand work in proposed frontiers project; potential for general industry uptake (with evolution) of chemical manipulation programs, supported by an expert
Growers monitoring temperature for use in farm management decisions	In orchard temperature logging capacity now present on farms representing at least one third of production	Potential to develop an app for estimating cool temperature floral induction condition to augment calculator for estimation of time of harvest maturity

Figure 5. Marcelo Amaral beside a recently tip pruned tree. Marcelo is a human resource outcome of MG22000. Photo by author.

Recommendations

The recommendations below are presented first as practical guidance for current Australian mango production, followed by priorities for future research.

Grower recommendations

- A grower group visit to the Petrolina region of Brazil, where mango flowering is induced in all months of the year, is recommended.

- Canopy management is crucial for manipulation of the timing of flowering. Cool exposure alone does not determine floral induction. Flush maturity, canopy synchrony, and warm interruptions during the early inductive period all affect whether flowering will occur. Programs of activity (irrigation/pruning/chemicals) should be developed specific to region and cultivar for a desired flowering time target.

- Floral induction can be anticipated, with use to guide timing of other orchard management practices, based on cool temperature conditions of time (hours) below a threshold temperature *x* [specifically: 120 to 130 h below 21.5 °C for 'B74' in Darwin, 15.0 °C for 'B74' in Far North Queensland, 18.3 °C for 'Honey Gold' in Darwin and 15.0 °C for 'Honey Gold' in Bungundarra].

- APVMA registration should be sought for application of PBZ to the final major vegetative flush, not to a fixed early post-harvest date (the current label only allows 'application is recommended once per year within four weeks after harvest and no later than mid-February'. For advancement of flowering in warm tropical systems, PBZ + K_2SO_4 + KNO_3 was the strongest overall program trialed, while PBZ + KNO_3 was the strongest simpler alternative.

- Ethephon can improve flowering response, with use before full flowering allowed in NT, QLD and WA under APVMA PER91560, but care in use is required to avoid negative effects. The risk of canopy injury increased at application rates above 200 ppm. GA_3 is not registered for use on mango and given that in the treatment combinations trialed, GA_3 did not provide a dependable flowering-delay outcome, it is not recommended that a permit be sought

- In calculation of GDD for fruit development to harvest maturity, use Tb = 12 °C and TB = 32 °C.

- Harvest windows of 1724–2017 GDD for 'B74', 1747–2083 for 'Honey Gold', 1606–1946 for 'Kensington Pride', 1531–1896 for 'Nam Dok Mai', and 1459–1743 for '1243' are recommended. Minimum harvest maturity targets of 1509 GDD for 'R2E2', 2211 for 'Keitt', 1670 for '1201' and 1670 for '4069' are recommended.

- Retain flesh colour as the main practical maturity anchor for Australian mango, with classes 7, 7, 7, 9, 9, 11, 11, 13 and 13 recommended as minimum maturity targets for 'Nam Dok Mai', 'B74' and 'KP', '1243', 'Honey Gold', '1201' and 'R2E2', '4069' and 'Keitt', respectively. Classes 7 and 11 were provisionally recommended for 'Lady Jane' and 'Agam', respectively.

- Use Pantone® Plastic Standard Chips for field assessment of cut-fruit flesh colour – specifically, 461C for class 7, 600C for class 9, 7403C for class 11, and 127C for class 13.

Future research recommendations

1. Improve understanding of terminal readiness by linking flowering response to flush age, carbohydrate status, water status, and related physiological markers. This should include testing whether simple field methods, including starch-iodine staining based approaches, can identify terminals that are ready to respond.
2. Continue molecular and physiological work during the early inductive window to differentiate terminals entering reproductive growth from terminals continuing to vegetative and mixed vegetative-reproductive expression.
3. Develop a grower-facing decision tool as a website or dashboard, that combines orchard temperature records and short-term forecast temperatures to inform timing of pruning and nitrate application.
4. Link flowering prediction and harvest prediction, with future work moving beyond separate flowering and maturity tools toward a single system that estimates likely harvest windows after flowering has been advanced, delayed, or synchronized. This will become increasingly important under warmer and more variable conditions, where flowering timing and fruit-development rate may both shift.

5. Validate the recommended temperature threshold for floral induction and the chemical-program recommendations across more seasons and more tropical regions, especially for cultivars where evidence is still limited, including 'KP', 'R2E2' and '1243'. Priority regions should be those with warmer winters and more frequent warm interruptions, such as Darwin, Katherine, Kununurra, Bowen and the Burdekin, rather than cooler or already better-defined systems such as Mareeba or southern Queensland.
6. Refine cultivar specific GDD maturity targets using flesh colour, SSC:TA > 7, NIR dry matter, and ripening behavior together, rather than relying on any one attribute alone. In orchard, flesh colour should remain the primary maturity guide, with a dry matter content value associated with the desired flesh colour established as the maturity target for a given orchard.
7. Continue harvest window GDD validation work for '1201', '4069', 'Lady Jane' and 'Agam' and other Australian-grown cultivars not fully covered, for which only indicative flesh-colour class placement were made.
8. Continue improving and testing methods for non-destructive assessment of fruit harvest maturity, especially for flesh colour, while retaining destructive assessment of flesh colour and non-invasive NIR based assessment of dry matter as ground-truth references until field-ready non-invasive methods reach required accuracy.
9. Test additional Pantone® Plastic Standard Chips, especially to confirm the provisional matches for grades 7, 11 and 15 (461 C, 7403 C and 129 C) and to identify better chip matches for grades 3 and 5, where current matches remain weak.

Refereed scientific publications

Journal article

Amaral, M., Walsh, K.B., Dickinson, G., McConchie, C., 2026, Growing Degree Day Targets for Fruit Development of Australian Mango Cultivars 2. Reconsideration of Tb and TB. Acta Horticulturae (accepted)

Intellectual property

No project IP or commercialisation to report.

Acknowledgements

We acknowledge the support of Gerhard Rossouw of Qld DPI in undertaking carbohydrate analyses, David Bin of Qld DPI in Walkamin research Station field trial assessments, Jashan Kaur of NT Government in post-harvest assessments, Elijah Staugas of WA DPI in Kununurra field trial assessments, and the general support of Upendra Shekhawat and Muhammad Sohail of NT Government.

The project was based on the involvement of many mango growers, orchard managers and collaborating farm representatives who contributed fruit, site access, logistical help and practical insight across the course of this research. This includes Tom Griggs, Kris Bailey of Acacia Hills Farm, Ian Groves of Groves Grown, Ray Courtice of Ontario Mangoes, Marie Piccone, Rory Nunes and Charlie Stone of the Manbulloo Group, Daniel Niceforo from Niceforo Group, Stephen and Rylan Scurr of Piñata Farms, Dale McDonald from Nutrano Group, Jeff Gooding from Golden Fruits, Ben Martin from Marto's Mangoes, Teresa Tan from NT Golden, Dave Gray from NT Quality Hay and Sam Collins from Blushing Acres.

Appendices

Appendix A. Paper for ISHS 2025 International Mango Symposium (Acta Horticulturae):

Growing Degree Day Targets for Fruit Development of Australian Mango Cultivars 2. Reconsideration of Tb and TB.

M. Amaral, K. Walsh, G. Dickinson, C. McConchie

Central Queensland University, Rockhampton, 4701, Australia

Abstract

Given flowering date and in-orchard air temperatures, accumulated growing degree days or heat units (GDD) can be used to forward estimate the time of harvest maturity to greater accuracy than use of calendar days. In a precursor study, we proposed new GDD targets for the Australian grown cultivars 'B74', Honey Gold and Keitt, with use of an upper temperature (TB) and lower base temperature (Tb) penalty on rate of maturation. In a continuation of this work, the current study validates the GDD targets for these cultivars and proposed targets for cultivars Nam Dok Mai, Kensington Pride, R2E2, NMBP 1201, NMBP 1243, NMBP 4069 and Agam. The recommendations are based on 15 min interval temperature data from in orchard-based sensors, and observations of fruit development from tagged panicles. The exercise was undertaken in multiple growing regions in Australia in the 2023 and 2024 seasons. Fruit were destructively sampled around the anticipated maturity date to establish the date of actual harvest maturity, based on specifications fruit mass (g), dry matter content, total soluble solids (TSS), acidity, and TSS:acidity ratio. Further samples were taken to determine time at which fruit reached a firmness of 2 kgf as an index of the 'hanging time' of the fruit. The optimum Tb was 12°C across the cultivars considered, while the optimum TB was generally 32°C but was higher (35°C) for Keitt. For those cultivars with previous GDD recommendations, the revised estimate differed by around 120 units, which is equivalent to 8 and 14 days at harvest time in Darwin and Bundaberg, respectively. Another season of work will be undertaken to validate the GDD targets for the cultivars with new maturity targets.

Keywords: count, heat units, GDD, prediction, size, YOLO

INTRODUCTION

Calculated accumulated growing degree days (GDD, also known as heat units or thermal time) has been recommended over the use of calendar days for estimation of the development time for many plant processes, including for estimation of the time between flowering and harvest maturity of mango fruit (Amaral et al 2023). Technology advances have made the use of on-farm air temperature monitoring stations and associated automated calculation of GDD units possible, simplifying adoption of the use of GDD in farm management.

Most previous mango GDD recommendations for fruit maturation have been based on an 'eyeball' estimation of flower stage, and have used the time of commercial harvest. Further, existing recommendations have generally been based on work in a single season. In recent work on the use of GDD for estimation of the mango fruit development period, Amaral et al. (2022) recommended a protocol for assessment of required GDD which involved the tagging of individual panicles, rather than assessment of an orchard block average, the use of local temperature monitoring stations, and destructive harvest of fruit around the anticipated maturity

date for assessment of maturity related attributes such as flesh colour. GDD targets were proposed for Australian grown cultivars 'B74', Honey Gold and Keitt.

The calculation of GDD in the Australian targets has involved use of the Arnold equation (eqn. 1) (Arnold, 1960) using a Tb of 10·C (Whiley and Hofman 2006) or 12·C (Moore at al 2016).

GDD = (Tmax+Tmin)/2 - Tb Eqn. 1

Amaral et al. (2023) recommended use of both a lower base temperature (Tb = 12o C) and an upper base temperature (TB = 32 ·C), following the calculations of Ometto (1981) (eqns 2-6). From work across multiple sites, a Tb of 12 ·C and a TB of 32 ·· was recommended, based on the procedure of Ometto 1981. However, these recommendations were based on mixed data of multiple cultivars, and thus effectively preliminary.

If TB>Tb>TM>Tm then GDD = 0. Eqn. 2

If TB>TM>Tm>Tb then GDD = ((Tmax-Tmin)/2) + (Tmin-Tb) Eqn. 3

If TB>TM>Tb>Tm then GDD = (((Tmax-Tb)2/2))/(2*(Tmax-Tmin)) Eqn. 4

If TM>TB>Tm>Tb then GDD = (2*(Tmax-Tmin)(Tmin-Tb)+(Tmax-Tmin)2 - (Tmax-TB)2)/ 2*(Tmax-Tmin) Eqn. x.5

If TM>TB>Tb>Tm then GDD = ½*[[Tmax-Tb)2-(Tmax-TB)2]/(Tmax-Tmin)] Eqn. 6

The current study extends the work of Amaral et al. (2022), to: (i) confirm the GDD recommendation on fruit development period for cultivars 'B74', Honey Gold and Keitt; (ii) provide recommendations on GDD for other cultivars of commercial relevance in Australia, viz., Nam Dok Mai, Kensington Pride, R2E2, NMBP 1201, NMBP 1243, NMBP 4069 and Agam; and (iii) recommend Tb and TB values on a cultivar specific basis. A protocol for GDD evaluation is also further developed and documented.

MATERIALS AND METHODS

Populations

Trials were established on commercial farms and research stations across Queensland and Northern Territory, Australia, involving latitudes from 12· to 23·, in three seasons and several cultivars (Table 1, 2). The work was superimposed onto experimental trials involving tagging flowering panicles and harvesting at different times to fine tune the GDD targets.

Table 1. GDD assessment sites.

Cultivar	Season	Orchards	Latitude	Longitude
Calypso, Agam, KP, Nam Dok Mai	2021/23/24	Acacia Hills, NT	-12.784128°	131.187722°
Honey Gold	2023/24	Lambells Lagoon, NT	-12.648013°	131.259296°
R2E2	2023	Lambells Lagoon, NT	-12.607131°	131.220785°
KP	2023	Fly Creek, NT	-12.791412°	131.096874°
KP, NMBP 1243	2023/24	Lake Bennett, NT	-12.963984°	131.171225°
NMBP 1243, NMBP 1201, NMBP 4069	2023/24	Katherine, NT	-14.465215°	132.318237°
Lady Jane®, Lady Grace®	2023/24	Katherine, NT	-14.641383°	132.469633°

NMBP 1243, NMBP 1201	2023	Kununurra, NT	-15.651449°	128.739589°
Calypso, KP	2023/24	Dimbulah, QLD	-17.126037°	144.988122°
Honey Gold	2023	Dimbulah, QLD	-17.164162°	145.091.099°
Calypso	2023	Dimbulah, QLD	-17.108429°	145.087386°
NMBP 1243, NMBP 4069, KP, R2E2	2023/24	Numbulwa, QLD	-17.115948°	145.096998°
Palmer®, Keitt	2023	Numbulwa, QLD	-17.107994°	145.096606°
Nam, R2E2, NMBP 1243, NMBP 1201, Agam, KP	2023/24	Walkamin, QLD	-17.138082°	145.428033°
KP, Nam Dok Mai, R2E2, Keitt, Honey Gold	2023/24	Mareeba, QLD	-17.011407°	145.511052°
KP, Nam Dok Mai, R2E2	2023/24	Bungalbellina, QLD	-15.012898°	150.647578°
		Rockhampton, QLD	-23.112982°	150.510674°

Panicle tagging and fruit harvest

The subtending stems of approximately 200 reproductive terminals at asparagus stage were tagged at each location using flagging tape (Brutus, China). In a few cases, asparagus stage was missed, so the Christmas tree stage was tagged. If more than one flowering event was followed in the same orchard, flagging tape of different colours was used. Sites were initially inspected weekly, with recording of panicle developmental stage (Figure 1). Tags were moved from the stem to the panicle after the fruit set.

Figure 1. Stages of development of flowering: (a) asparagus stage, (b) elongation stage , (c) Christmas tree stage, and (d) fruit set.

For B74, Honey Gold and Keitt, fruit was destructively sampled at, and approximately 100 GDD before and after, the recommended GDD targets of 1728, 1740 and 1680 (with Tb 12 and TB 32·C as proposed by Amaral et al. 2023). For Kensington Pride and R2E2, the GDD targets established by Dimbulah (1997) and Moore (2016) were used, i.e., 1600 and 1800 (with Tb 12), respectively.

For cultivars Nam Dok Mai, NMBP 1243 (commercially known as 'Yes'), NMBP 1201 ('4h Ha'), NMBP 4069 ('Now') and Agam ('Scarlett Delight'), fruit was harvested from 1400 GDD (using Tb 12 and TB 32) at weekly intervals until harvest maturity was reached, generally for between two and six weeks. The number of fruit harvested per week varied depending on fruit availability, at between 5 and 20 per weekly harvest.

For some populations (Table 1), fruit harvest continued at weekly intervals until fruit reached a firmness of 2-3 kg f (as assessed using a pocket dial penetrometer, equipped with a 6.4 mm diameter plunger). This value represents the minimum firmness at which fruit are acceptable for commercial harvest (AMSA, 2016), i.e., have an acceptable shelf life and are not prone to damage in transit.

Temperature monitoring

For each site, daily maximum and minimum temperatures were extracted from the log of a Lolin (Long Range radio) enabled temperature sensor mounted in a weather screen (SensorScout, Rockhampton, Australia) mounted on a star-picket 1.2 m above grass-covered ground (Figure 2), an exception was the Katherine Research Station, where an on-site Geonmag (Goondiwindi, Australia) weather station was used. Sensors were located approximately 10 from orchard trees. Sensor data was recorded at 15 min intervals.

Figure 2. (a, b) Tagging of terminals with reproductive growth, using different colours of tape for tagging in different weeks. (c) In-orchard temperature sensor near on Pallens trees with and tags on reproductive terminals at asparagus stage.

Assessment of maturity attributes

Fruit was harvested and assessed hard green with no more than 4 days from original harvest. Fruit weight and linear dimensions of length (L), width (W) and thickness (T) were recorded. A 400-1000 nm absorbance spectrum was then acquired of the intact fruit using a handheld near infrared spectrometer (F750, Felix Instruments, Camas, WA, USA) employing an interactance optical geometry. A spectrum was acquired from a mid-position on each cheek of each fruit.

Figure 3. Flesh cut direction and assessment.

The two 'cheeks' of the fruit were then cut longitudinally, approximately 2 cm from the fruit seed (Figure 3). The flesh colour of each cheek was assessed based the Calypso colour cards (Perfection Fresh, 2019 print) with scores of 3, 5, 7, 9, 11, and addition of an extension of scores 13, 15 and 17 (Amaral et al 2023) printed using a commercial printing service (Image Science, Melbourne,

Australia). These cards span a range from a white-green (card 1) to a yellow-orange (card 17). For some populations, flesh colour was also assessed as CIE-Lab using a Chroma Meter (CR-400, Konica Minolta). Hue angle was calculated as tan⁻¹ (B/ A).

A cylindrical corer (of 2 cm diameter) was used to take a core from the centre of each cheek. The skin was peeled from each core, and the core then trimmed to 2 cm length from the skin side). This sample was weighed and then dehydrated using a fan forve dehydrator (Excalyr1000, Australia) at 60 °C for 48 hours before re-weighing. A precision balance (0.001 g resolution) (OL YY) used for both fresh and dry weight assessment, with dry matter content calculated as Dry Weight/Fresh Weight*100.

Flesh firmness assessed using pocket dial penetrometer (0-10 kg scale), equipped with a 6.4 mm diameter plunger after cutting a section of the skin with a blade. The remaining pulp of each cheek was squeezed using a garlic press or by hand after wrapping in muslin. After resting, a juice sample was used for assessment of Soluble Solids Content (SSC) using a digital refractometer (Atago RTM1,acidity digital refractometer, Japan), another sample (1 mL) was diluted into 50 mL with distilled water and assessed for Acidity assessment using the same Atago meter. To check the Atago acidity estimations, (5 mL) juice samples of 10 fruit were titrated using 0.1 N NaOH, with comparison to a 1 %w/v citric acid standard. The Atago acidity meter was also used in assessment of standards consisting of citric acid at concentrations of 0, 0.2, 0.4, 0.8, 1.6, 3.2 %w/v in either 1 or 10% w/v sucrose. Other fruit (approximately n=10) from each harvest event were held at 22 °C for evaluation of ripening time. Fruit was cut when soft to touch, with assessment of attributes as for the at-harvest fruit.

Time to ripen

A time-to-ripen assessment was performed in the 2024 season using fruit at a range of maturities (as indexed by BrixAcidity,DM%, flesh colour and GDD). Five to ten fruit of each maturation stage were held at 20-24 °C until soft to touch (penetrometer firmness < 2.0 kgf). Fruit were then cut longitudinally and firmness (kg), flesh colour (CIE-Lab), SSC and acidity was then measured using the same methodology as described in the previous section.

GDD and estimation of Tb and TB

The values of Tb and TB used in the GDD calculations was optimized following the method of Ometto 1981 (Equation 2-6). In brief, for each of three cultivars (KP, Honey Gold and R2E2) the GDD increment between asparagus stage and fruit harvest maturity was calculated using equation 1 for three sites (Darwin, Brodsdale and Bungunderra) using Tb values varied from 1 to 20 °C at intervals of 0.3 °C. The coefficient of variation (CV) on GDD across the multiple sites was plotted against Tb value, and the optimal Tb chosen as the value with lowest CV. TB values were then varied from 25 to 37 °C at intervals of 0.3 °C while using the optimized Tb for each cultivar for the calculation of GDD increment from asparagus stage to harvest maturity for the same sites and cultivars, using equations. 2-6. . The optimal TB value for a cultivar was chosen based onminimized CV, as for Tb. The sites were chosen to represent a spread of latitudes in which mango is commercially grown, while the cultivars were chosen as representatives of early, mid and late maturation types.

R2E2	1800	Moore et al. 2018	1600	1641	in report	earlier
Honey Gold	1800 Yellow Belly	Moore 2014	1749	1721	validated	earlier
Kent	NA	Moore, Hanna 2013 (different Tb)	1,200	974	validated	
Tribute	NA	NA	2,200	NA	in report	counter to Kent, but lower long term
New Zee Kay	NA	NA	1600	1668	in report	
NMBP 1,250	NA	Reported end time 2017 (different Tb)	1400	1251	in report	1-2 weeks before KP (2 former the same time), but variably the later time KP's
NMBP 1,350	NA	NA	1400	NA	in report	counter to KP
NMBP 4069	NA	NA	1400	NA	in report	counter to R2E2
Agasi	NA	NA	1400	1411	in report	
Lady Jane	NA	NA	1272	NA	in report	counter to KP
Lady Anne	NA	NA	1400	NA	in report	counter to KP

Harvest window

A 'harvest window' was estimated for the 13 cultivars as the GDD window between harvest maturity and tree-ripe fruit (flesh firmness of 2 kgf) (Fig. 6). While tree-ripe is obviously beyond commercial harvest, this presentation gives an idea of variation between cultivars in potential harvest window. Such information has practical value in terms of farm design, with plantings of trees of different cultivars to achieve an extended production window. Note that this does not consider the variation in the time of flowering (xxx), with some varieties can require more 'time' and 'cool weather' to flower than others. Kent represents a benchmark for its extended window.

RESULTS AND DISCUSSION

Tb and TB recommendations

The estimated optimum Tb was effectively the same for three cultivars, with the CV 11 and 12 °C (Fig. 4). The use of 12 °C for Tb is recommended as this value is well-established in the Australian industry.

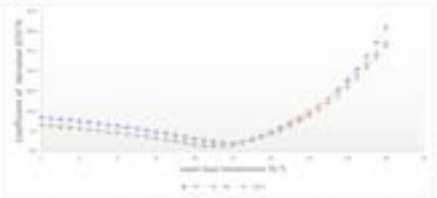


Figure 2. Cross validation (CV) metric for Tb values, with CV calculated from estimated harvest maturity GDD values from a number of sites/seasons. The Tb with lowest CV is recommended. Results are presented for three cultivars: Kensington Pride (blue), Honey Gold (orange) and R2E2 (grey).

The optimal TB (least maximum temperature) was 32 °C for all cultivars except Kent, which tolerated higher temperatures (TB of 35 °C recommended) (graph not shown).

GDD recommendations

The recommended GDD varied from previous recommendations, being earlier for some cultivars and later for others (Table 2). The variation between old and new recommendations was around 120 units, which is equivalent to 8 and 14 days at harvest time in Darwin and Bundaberg, respectively.

Table 2. Old and new recommendations for GDD from flowering (asparagus stage) to fruit maturity, and for hanging time for 13 cultivars. All GDD calculated with Tb = 12 and TB = 32 °C, except for Kent, for which TB of 35 °C was used.

#	Old GDD target	Source	New GDD target	Hanging time (GDD)	Status (data quality)	Comments
	1400	Scudellaro et al. (2017	1550	200	validated	earlier than previous recommendations
Alphon	1400	Moore et al. 2018	1728	300	validated	later

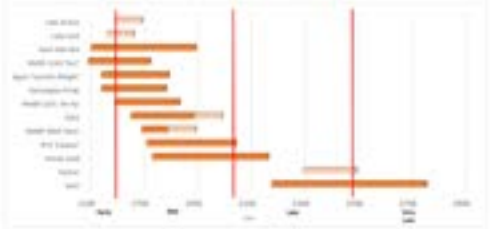


Figure 3. Assessed 'harvest windows', with harvest starting at the GDD required to achieve cultivar specific targets for flesh colour, Brix to dry matter ratio and total acidity, and harvest end based on GDD at which flesh firmness reached 2 kgf. Shaded bars represent end dates based on a linear extrapolation of the decrease in flesh firmness from the last measurements of firmness. Red lines represent a general definition of early, mid, late and very late season varieties.

CONCLUSIONS

The following suggestions are made:

(i) The Upper T (Ometto 1981) method is recommended for use in Australia, with a Tb of 12 °C and TB of 32 °C confirmed for cultivars Kensington Pride, Honey Gold and R2E2 and recommended for use with other cultivars until assessed otherwise. For Kent, a TB of 35 °C is recommended.

(ii) The GDD targets of 1550, 1728, 1740 and 2185 were validated for the cultivars KP, Calypso, Honey Gold and Kent, respectively, which are the main mango cultivars in production in Australia. of further work is required to confirm the target for R2E2 (at between 1650-1790 GDD).

(iii) GDD targets of 1300, 1450, 1550, 1600, 1550 were recommended for Nam Dok Mai, NMBP 1243, NMBP 1351, NMBP 4069 and Agasi. However, validation of these recommendations in another season is proposed.

(iv) A procedure was established based on terminal tagging, sequential harvests of fruit and assessment of time-to-ripen for assessment of GDD targets for maturation time and for an index of the 'harvest window'.

(v) In-orchard LoRA enabled temperature sensors are recommended for estimating harvest time using GDD

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Appendix B. Presentations at AMIA roadshows, 'mini-research symposium'

Pre-season Mango Roadshows Bring Industry Together

From August to October, the Australian Mangoes team hit the road to connect with growers and industry stakeholders across the country in the lead-up to the 2025-26 mango season. Roadshows were held in Darwin, Katherine, Kununurra, Mareeba, Bowen, Rockhampton and Bundaberg, bringing together hundreds of attendees for presentations, updates, and on-farm demonstrations.

In the Northern Territory and Kununurra, growers heard from industry speakers on domestic market access, mango twig tip dieback, crop forecasting, and the latest R&D aimed at improving fruit quality and productivity. Highlights included a presentation from Marcelo Amaral (CQU) on flowering manipulation trials and in-field demonstrations of new ag-tech developments such as the Orion Imager, capable of mapping and counting fruit within orchards, and the self-driving Burro vehicle for autonomous navigation.

The Queensland roadshows featured presentations from Australian Mangoes CEO Trevor Dunmall on key industry matters, marketing and retail engagement. Industry Development Officer Adelaide Belyea introduced new grower resources including the updated Quality Assessment Manual and Mango Nutritional Guide, the MRL App's move to a new platform, and a new health and wellbeing webpage. She also outlined upcoming demonstration site projects, changes to crop forecasting, and opportunities to participate in a joint mapping project with the University of New England.

Ebony Feehney, Adelaide Belyea, and Debbie Nucifora

Guest speakers from the Queensland Agricultural Workforce Network provided workforce updates, while Andrew Macnish and John Archer (QDPI) and Michael Tatlock (Escavox) presented a new shelf-life prediction calculator to help manage fruit quality throughout the supply chain. Field activities included a drone spray demonstration by Luke Jurgens of NQ Aerovation in Bowen and farm tours with John and Debbie Nucifora in Arriga, Daniel Rye in Rockhampton and Derek Foley in Bundaberg. We extend our thanks to everyone who contributed to the success of this year's pre-season roadshows, including our hosts, speakers, attendees, and event sponsors—Contrak, Freshtrack, Omnia, Syngenta, Nutrien Ag Solutions and MAF Oceania —for their generous support.

Mini Mango Research Symposium

Thursday 10 April 2025
12:00 – 17:00
Humpty Doo Golf Club
565 Pioneer Drive, Humpty Doo NT 0836

Australian Mangoes invites mango growers to take part in a Mini Mango Research Symposium on Thursday, April 10. Hear from leading mango researchers across the country and provide input into the direction of future mango research.

- **View the agenda** click here
- **To R·S·V·P, contact Celine:** celine@mangoes.net.au **or 0457 555 929.**

Funding for this event has been provided through a grant facilitated by the NFF Hort Council with funds from the Department of Agriculture, Fisheries and Forestry.

Regional Workshops Help Build Links Between Growers and Researchers

The team at Australian Mangoes recently hosted four regional research workshops aimed at strengthening the connection between researchers and growers. Held in Darwin, Carnarvon, Ayr and Mareeba, the series began in April in Darwin. The workshops featured presentations from QDPI and NTDAF researchers and provided opportunities for growers to contribute input into future research priorities. While topics and discussions varied between each location, they included:

- Carbohydrates and impact of fruit retention/fruit drop
- Current pest and disease management
- Orchard intensification
- Floral manipulation
- Temperature and impact on pollination
- Current rootstock research
- New varieties
- Tissue culture research

Presenters at the workshops included Chelsea Moore and Jashan Kaur from NTDAF, Gerhard Rossouw, Ryan Orr and Asjad Ali from QDPI, Marcelo Amaral from CQU and Kamila Zeliatdinova from Trade Investment Queensland.

Group discussion in Darwin.

Marcelo Amaral, Kris Bailey, Jashan Kaur, Upendra Shakhawat and Keiko Jacobsen.

Breakout session in Darwin.

National Horticulture Road Show

The National Horticulture Roadshow was delivered by the NFF Horticulture Council with funding from the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF) through the Showcasing Australian Horticulture grant.

Networking in Bowen/Burdekin.

Appendix C. Article for AMIA Mango Matters (Autumn 2025)

mm-autumn-25-web-v3.pdf

Growing Degree Day Targets for Fruit Development of Australian Mango Cultivars – A New Chapter

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Why?

Fruit development is influenced by both time and temperature. Heat units, also known as Growing Degree Days (GDD), measured from time of flowering, provide a more accurate indication of when fruit will mature than calendar days. For example, a KP tree that flowers on 1st June in both Darwin and Bundaberg will mature on 25 September and 6 December, respectively, in an 'average year' due to the cooler conditions at the southern site.

In a previous article in 2022, we introduced an online calculator that helps estimate fruit maturation timing based on heat units. This tool uses flowering dates and in-orchard temperature data collected remotely. A key part of this calculation is the 'target' heat unit value, which is specific to each mango variety. However, past recommendations for mango heat units have often been based on rough estimates of average orchard flowering and harvest times, typically from a single season and region. Additionally, there has been little research to confirm the 'minimum temperature threshold' (Tb), below which fruit development is assumed to stop, or the 'maximum temperature threshold' (TB), above which maturation slows down.

Our current work seeks to confirm and extend our previous recommendations, with focus on Australian-grown cultivars Honey Gold, Keitt, Nam Dok Mai, Kensington Pride, R2E2, NMBP 1201, NMBP 1243 and NMBP 4069. For each cultivar, we aim to determine both the optimal heat unit target and the most accurate minimum (Tb) and maximum (TB) temperature thresholds.

How?

To determine an accurate heat unit target for each mango variety, we used in-orchard temperature monitoring stations rather than relying on BOM or farm stations located farther from the orchard.

Rather than estimating flowering stages across an entire block, we tagged individual panicles to track development more precisely. Fruit from these tagged panicles was harvested at multiple points around the expected maturity date, based on the existing recommended Growing Degree Days (GDD) targets (see Amaral et al. 2022, Figure 1).

Figure 1. (A) The protocol for establishing a heat unit target for a cultivar involved tagging of individual panicles and maturity assessment non-destructive (b) and destructive (c) of resulting fruit at several dates, to establish the date of optimum maturity. Additional treatments had a ripening library (d) to support maturity and define fruit shelf life. Local temperature was logged using a SensorHost (Rockhampton) sensor.

Each harvest included 5 to 20 fruit, with measurements of NIR-dry matter (DM), oven-DM, fruit size, soluble solids concentration (SSC), acidity, flesh colour, and firmness used to determine when the fruit had reached optimal harvest maturity.

We also assessed the 'hanging time' of some fruit populations by continuing harvests beyond maturity until the fruit reached a firmness of 2kgf (measured using a penetrometer with a 12mm diameter plunger), which is 'firm eating stage'.

LoRa (long range radio) enabled temperature sensors were mounted in weather screens (SensorHost, Rockhampton, Australia) mounted on a star-picket 1.2m above grass covered ground. Sensors were located approximately 5m from orchard trees. Sensor data was recorded at 15 minute intervals. An exception was the Katherine Research Station, where an on-site GoannaAg (Adelaide, Australia) weather station was used.

The GDD between flowering and fruit harvest maturity was calculated from the daily maximum and minimum temperatures for each trial site, using different values of Tb and TB.

Where and When?

Trials were conducted on commercial farms and on two research stations in Queensland and the Northern Territory, spanning latitudes from 12° to 23°S. The study was carried out over three seasons (2021, 2023, and 2024) and included multiple cultivars (Table 1).

At several sites, the research was integrated with another study where trees were tip-pruned at monthly intervals, resulting in trees flowering at different times.

Region	Sites	Cultivars	Season
Darwin, NT	5	KP, R2E2, Honey Gold, Nam Dok Mai	2021, 2023, 2024
Katherine, NT	2	NMBP 1243, NMBP 1201, NMBP 4069, Lady Jane, Lady Grace	2023, 2024
Kununurra, WA	1	NMBP 1243, NMBP 1201	2023
Mareeba, QLD	5	KP, R2E2, Honey Gold, Keitt, Palmer, NMBP 1243, NMBP 1201, NMBP 4069	2023, 2024
Rockhampton, QLD	2	KP, R2E2, Honey Gold, Keitt, Nam Dok Mai	2021, 2023, 2024

Table 1. GDD assessment sites

What?

Tb and TB recommendations

The variation in the calculated GDD values for a given cultivar across different locations was measured using the 'Coefficient of Variation' (standard deviation divided by mean). This was done using a range of Tb and then TB values in the calculation of GDD, calculated from estimated harvest maturity GDD values from three sites/seasons for each cultivar. The Tb and TB that resulted in the lowest variation in GDD across locations were identified as the most reliable and recommended for use in future GDD calculations.

The Tb giving the lowest variation was similar for three cultivars (KP, HG and R2E2), at between 11°C and 12°C (Figure 2). The use of 12°C for Tb is recommended as this value is already in use in the Australian industry.

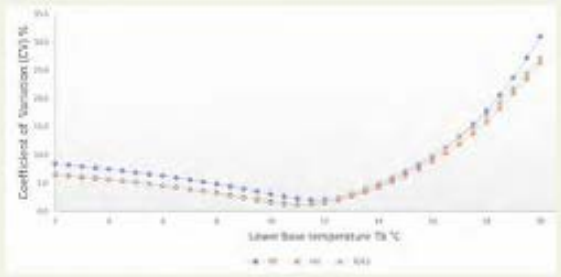

Figure 2. Variation (coefficient of variation) associated with using different Tb values for three cultivars, calculated from estimated harvest maturity GDD values from three sites/seasons for each cultivar.

The optimal TB (basal maximum temperature) was 32°C (above which maturation is delayed with increasing temperature) for KP, HG and R2E2. Keitt appeared to tolerate a higher temperature (higher TB) but further work is required to confirm this result.

GDD recommendations

The suggested GDD values for fruit maturation varied from previous recommendations, being earlier for some cultivars and later for others (Table 2).

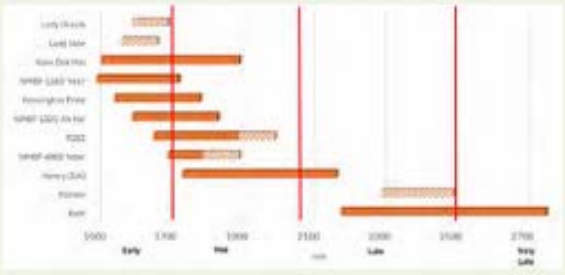

Figure 3. Variation in the GDD window between harvest maturity (based on flesh colour, brix to dry matter ratio and total acidity) and fruit ripening on-tree (based on flesh firmness of 2 kgf). Shaded bars represent end dates based on a linear extrapolation of the decrease in flesh firmness for the last actual measurement of firmness. Red lines represent a general definition of early, mid, late and very late season varieties.

Cultivar	Old GDD target	Source	New GDD target	Hanging time (GDD)	Status (data quality)	Comment
KP	1600	Diczbalis et al 1997	1550	250	validated	earlier than previous recommendation
R2E2	1800	Moore et al 2010	1660	240	to repeat	earlier, but need to confirm another year
Honey Gold	1800 *adjusted	Winton 2013	1740	330	validated	earlier
Keitt	2100	Ozuna-Garcia 2013 (different Tb/flower stage)	2185	576	validated	
Palmer	NA	NA	2200	NA	to repeat	similar to Keitt, but lower hanging time
Nam Dok Mai	NA	NA	1500	388	to repeat	depends on use, usually harvested and commercialized as green mango (could be before 1500 GDD)
NMBP 1243	NA	Henriod and Sole, 2017 (different Tb)	1450	250	to repeat	1-2 weeks before KP (if flower at the same time), but usually flower later than KPs
NMBP 1201	NA	NA	1600	NA	to repeat	similar to KP
NMBP 4069	NA	NA	1650	NA	to repeat	similar to R2E2
Lady Jane	NA	NA	1570	NA	to repeat	similar to KP
Lady Grace	NA	NA	1650	NA	to repeat	similar to KP

Table 2. Old and new recommendations for GDD from flowering (asparagus stage) to fruit maturity, and from maturity to ripe-on-tree (hanging time), for 13 cultivars. All GDD calculated with Tb = 12 and TB = 32. At harvest time, 100 GDD is equivalent to 1 - 1.5 calendar weeks

The variation between old and new recommendations was around 120 units, which is equivalent to 8 and 14 days at harvest time in Darwin and Bundaberg, respectively.

Harvest window

A 'harvest window' was presented for 11 cultivars as the GDD window between that at harvest maturity and that associated with tree-ripe fruit (flesh firmness of 2 kgf) (Figure 3). While tree-ripe is obviously beyond commercial harvest, this presentation gives an idea of variation between cultivars in potential harvest window. Such information has practical value in terms of farm design, with plantings of trees of different cultivars to achieve an extended production window. Note that this does not consider the variation in the time of flowering times, with some varieties requiring more 'time' and 'cool weather' to flower than others.

What next?

Work will continue in the upcoming season to validate the recommendations. Other work is ongoing around manipulation of floral induction.

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Hort Innovation MANGO FUND

Appendix D. PhD thesis Marcelo Amaral

Managing Mango for a Changing Climate: Manipulating Flowering and Harvest Timing in Australian Mango Production

Submitted 13 April, 2026

Full thesis will be available at: https://acquire.cqu.edu.au/

Abstract

The aim of this thesis was to improve the management of flowering, harvest timing, and maturity assessment in Australian mango (*Mangifera indica* L.) production. A review of the literature on mango flowering physiology and management options highlighted the interacting roles of temperature, water status, carbohydrate reserves, canopy condition, and plant growth regulators in floral induction. Four sets of experimental activity were then undertaken. First, growing degree day targets for fruit development from flowering to minimum and maximum harvest maturity were validated for 'B74', 'Honey Gold', 'Keitt' and 'Kensington Pride' using data from 86 populations across 37 site-season combinations, and new targets were established for 'R2E2', '1243', 'Nam Dok Mai', '1201' and '4069'. A common thermal-time model using Tb = 12 °C and TB = 32 °C was recommended, and the harvest window was defined using flesh colour, SSC:TA, firmness and ripening time. Second, the temperature conditions required for floral induction after tip pruning were quantified using data collected across three seasons, eight orchard sites, and 4,530 tagged terminals, with about five pruning dates per population. The best predictor of floral development was hours below a 'threshold temperature' (x) during bud development, tempered by warm interruptions. Region had a stronger influence on fitted x values than season. An x of 21.5 °C was established for 'B74' in Darwin and 15.0 °C in Far North Queensland, and 18.3 °C for 'Honey Gold' in Darwin and 15.0 °C in Bungundarra, with flowering associated with 120 to 130 h below x. Third, chemical strategies to advance or delay flowering were evaluated across five production regions over three seasons. For advancement, PBZ-based programs were most effective when PBZ was applied at the final major vegetative flush, with PBZ + K_2SO_4 + KNO_3 generally the strongest treatment and PBZ + KNO_3 the best simplified option. In Darwin, the PBZ + K_2SO_4 + KNO_3 program increased flowering in 'Honey Gold' from 0.52 to 0.88 of terminals, increased yield from 28.7 to 87.0 fruit tree^{-1}, and advanced time to 50% flowering by 42 d. Similar nitrate-based PBZ programs also improved flowering, synchrony and yield in Darwin 'B74', advancing flowering by about two weeks. Fourth, an extended colour-card series was recommended for assessing flesh colour, with minimum flesh-colour targets of 7 for 'Nam Dok Mai', 'B74', and 'KP'; 9 for '1243' and 'Honey Gold'; 11 for '1201' and 'R2E2'; and 13 for '4069' and 'Keitt'. Pantone Plastic Standard Chips 461 C, 600 C, 7403 C, and 127 C were recommended, based on ΔEab measurements, as robust field aids for flesh colour assessment.