

Influence of Pre-Harvest Calcium Sprays on Shelf Life and Firmness of Mango cv. Banganapalli

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ABSTRACT

Pre-harvest sprays of calcium salts are widely recommended to growers as a way of keeping fruit firmer and extending shelf life, and mango, with its short postharvest life and demanding export markets, is an obvious candidate. This narrative review asks how strong the case is for Banganapalli, a major commercial cultivar of southern India. It draws on published work on calcium transport into fruit, on the binding of calcium in the cell wall, on foliar and fruit uptake of nutrient salts, and on calcium-related disorders in apple, tomato, cherry and peach, and it reports no new data. The biological argument is coherent: calcium cross-links pectin, so a better-supplied wall should resist softening. The practical argument is weaker. Calcium reaches fruit slowly and mostly early in development, uptake through the skin is partial, and reported responses depend on cultivar, season, formulation and timing. We could not identify cultivar-specific evidence for Banganapalli that we could cite with confidence, and the review says so plainly. The risk of leaf and fruit injury, and of visible residue, also has to be weighed against any gain. The review concludes that modest benefits are plausible but unproven for this cultivar, and it sets out the measurements, replication and reporting that a convincing orchard trial would need.

Keywords: Mango; Banganapalli; Calcium sprays; Fruit firmness; Shelf life; Cell wall; Narrative review

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1. Introduction

Mango is among the most widely grown tropical fruits, and a ripe one is among the most perishable. For a grower, the practical limit on shelf life is usually not flavour but firmness: fruit that soften too quickly bruise in handling, travel badly and lose their appeal on the stall before a buyer has chosen them [1]. Banganapalli, a large-fruited cultivar grown mainly in southern India, is traded widely and handled by many hands between orchard and consumer, so any inexpensive way of slowing softening is of obvious

interest.

Calcium has long been the first nutrient that advisers reach for. It is a structural component of the cell wall and a regulator of many cellular processes [2, 3], and shortages of calcium in the fruit have been linked to well-known disorders in other crops, bitter pit of apple being the classic case [4]. A spray of a calcium salt in the weeks before harvest is cheap to apply with equipment a grower already owns, and the story that goes with it is easy to tell: more calcium in the fruit, stronger walls, firmer fruit, longer shelf life.

Each link in that story is plausible. None of them is guaranteed. Calcium moves into fruit slowly and mostly early in development [5, 6], a spray applied to the surface has to cross a cuticle that is not built to admit charged ions [7, 8], and what ends up in the flesh depends on cultivar, season, tree and formulation. We have also not found cultivar-specific evidence for Banganapalli that we can cite with confidence, and we say so here at the outset instead of leaving the reader to discover it. The risks of leaf scorch, fruit injury and visible residue are real too, and belong in the same ledger as the benefits. The aim is a fair account of what is known, and of what is merely repeated.

This article is a narrative review. It brings together published work on calcium physiology, cell wall biochemistry, foliar uptake and calcium-related disorders in other fruit, and it asks what that body of work can honestly tell us about pre-harvest calcium sprays on Banganapalli mango. It reports no new data and gives no numerical effect sizes, because we could not check any such figures against their primary sources for this article.

2. Literature Review

2.1 Calcium in the Plant and in the Fruit

Calcium serves three broad purposes in plants: it bridges components of the cell wall, it stabilises membranes, and, at very low free concentrations, it acts as a signal inside cells [2, 3]. Calcium and its sensors have also been implicated in the control of fruit ripening [9]. The structural role is the one that matters for firmness, and it depends on calcium that sits in the wall, not on calcium that is merely present somewhere in the tissue.

Calcium reaches a fruit mainly in the xylem sap and is poorly mobile in the phloem, which means that it cannot be pulled out of old leaves and sent on to the fruit when the fruit needs it [2, 5]. Transpiring leaves compete strongly for the xylem supply, and a young fruit that is growing quickly can find its demand outrunning what arrives, a situation proposed as the basis of blossom-end rot in tomato [10]. As fruit enlarge, the share of the total calcium that they receive tends to fall, and the concentration in the flesh is diluted by growth [5, 6]. The practical meaning is that the early weeks of fruit growth are when the tissue is most open to calcium, and the late weeks are when most growers spray.

Mango fruit follow the general pattern in broad outline. Studies of mineral composition through fruit growth show that concentrations change as the fruit develops and respond to management

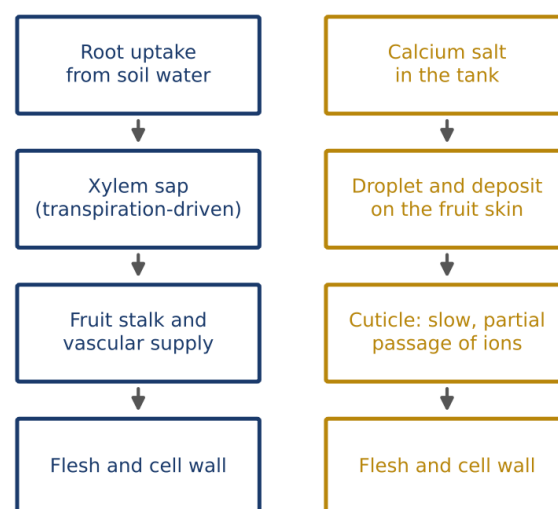
factors such as the number of leaves per fruit and the irrigation supply [11], and wider overviews list pre-harvest factors that influence both growth and later behaviour in storage [1]. A crop that is heavily loaded, or a tree that is vigorous and shaded, may therefore deliver less calcium per fruit than a lightly cropped one regardless of what is sprayed, a point that is easily lost when a spray is credited with differences that the crop load created. Table 1 and Figure 1 set out the main routes and constraints and what each implies for a spray programme.

Table 1. Routes and constraints on calcium reaching the fruit, and what they imply for sprays.

Route or factor	What the literature indicates	Implication for sprays
Xylem supply	Main route of calcium into fruit; relative supply falls as fruit expand [5, 6]	Early fruit are most receptive; late sprays meet a fruit that takes up little
Phloem	Calcium is poorly mobile in phloem [2, 5]	Leaf-applied calcium is not carried on to fruit
Competing sinks	Leaves and vigorous shoots draw calcium away from fruit [5, 10]	Canopy and crop load can offset a spray
Cuticle	Charged ions cross by slow, polar pathways [7, 26]	Wetting, humidity and salt choice matter; uptake is partial
Cell wall binding	Calcium bridges de-esterified pectin [12, 15]	Only wall-bound calcium helps firmness, not salt on the skin

Note: Qualitative summary of the cited physiological literature; it does not describe any single orchard or cultivar.

Route A: from the soil Route B: from the spray



Schematic of routes, not data; box size carries no meaning

Figure 1. Two routes by which calcium may reach the fruit flesh (schematic, not data).

2.2 Calcium and the Cell Wall

Pectin, a family of acidic polysaccharides rich in galacturonic acid, forms the gel in which cellulose and hemicellulose are embedded and is the main component of the middle lamella that glues neighbouring cells together [12, 13]. When pectin is de-esterified by pectin methylesterase, free carboxyl groups appear that can be bridged by calcium [14], and the cross-links so formed were described long ago in the egg-box model [15]. Walls that are well cross-linked resist the forces that separate cells, which is the physical basis of firmness [16].

Softening is more than a loss of calcium, however. During ripening, pectin is solubilised and shortened, hemicelluloses are modified, and the middle lamella loosens, driven by a set of wall-modifying enzymes whose action is coordinated by ripening hormones [17, 18, 19]. Imaging of pectin at the nanometre scale shows how extensively its structure changes as fruit soften [20], and work on mango pulp has linked softening to changes in wall polysaccharides and the enzymes that act on them [21]. Added calcium may restrain some of this, but it does not stop the programme that is taking the wall apart. Fruit that soften quickly after harvest are rarely rescued by anything done in the packhouse.

That programme is switched on by ripening signals, in climacteric fruit such as mango chiefly ethylene, within a wider genetic regulation of fruit development [22, 23, 24, 25]. A fruit stored warm, or exposed to ethylene, will soften on the schedule that its biology and environment dictate, and a modest difference in wall calcium acts on top of that schedule. This is why any benefit of calcium for shelf life should be expected to be incremental, and why its size depends so much on how the fruit are stored and ripened afterwards.

2.3 Getting Calcium Through the Skin

The cuticle covering leaves and fruit is a waxy, largely hydrophobic barrier. Charged and polar solutes such as calcium ions are thought to cross it slowly through polar pathways, whose properties are only partly understood [7, 26]. Reviews of foliar fertilisation stress that uptake of such solutes depends on the formulation, on the humidity and wetness that keep the deposit dissolved, on the age and structure of the surface, and on the plant species [27]. What happens to a foliar-applied nutrient after it is applied, and how much of it ends up where it is wanted, remains uncertain for many nutrients [8].

The cuticle also matters in its own right for postharvest life. It limits water loss and shapes how fruit respond to pathogens in storage, so differences in cuticle between cultivars can affect shelf life independently of the cell wall [28, 29]. For a mango cultivar, this has two consequences. A thicker or more continuous cuticle may slow uptake from a spray and may also help keeping quality for reasons unrelated to calcium; whether Banganapalli differs from other cultivars in either respect, we could not establish.

Spraying has costs as well as benefits. Calcium salts applied at high concentration can scorch leaves and mark fruit, and the choice of salt and the addition of wetting agents influence both uptake and injury [8, 27]. Calcium is a plant nutrient and is not generally regarded as a residue hazard in the way some agrochemicals are, but a pale deposit on the skin of a fruit sold on appearance is a commercial problem, and sprays mixed with other products in the tank need to be checked for compatibility before use. This is why the same spray can look useful in one report and unremarkable in the next.

2.4 Evidence from Other Fruit

Most of what is known about calcium sprays comes from fruit other than mango. In apple, the link between low fruit calcium and bitter pit has been studied for decades, and the disorder is understood to involve other factors as well [4]; the balance between nitrogen and calcium has been argued to matter for postharvest quality and disease resistance [30]. In tomato, blossom-end rot has been debated as a disorder of calcium supply or of the stresses that restrict it [10, 31]. Sweet cherry has been the subject of a thorough review of calcium physiology, and the literature on its sprays does not reduce to a simple rule [32].

Peach is a useful comparison because the experimental questions are close to ours: calcium treatment altered tissue calcium, wall properties and the incidence of flesh browning, although the treatment in that work was applied after harvest, not before [33]. Broader reviews of the role of calcium in postharvest life describe both pre- and postharvest applications and conclude that responses depend on many conditions [34]. Table 2 sets out the main disorders and what they do and do not tell us about mango. Read this way, the absence of an effect in a small trial is not evidence that there is none.

2.5 Mango and Banganapalli

Pre-harvest calcium sprays on mango have been tested in several producing countries, and the

usual outcomes of interest are fruit firmness, weight loss, ripening time and the incidence of rots and internal disorders. We do not cite individual mango trials in this review, because we could not check their numerical results or their designs against the original papers, and we prefer silence to a figure that might be wrong. The general mango literature is nonetheless enough to show what a trial would be up against: fruit mineral content moves with crop load, irrigation and tree vigour [1, 11], and softening is driven by a coordinated set of wall changes in the ripening pulp [21].

Table 2. Calcium-related disorders reported in other fruit and the position for mango.

Fruit and disorder	Calcium link in the literature	Position for mango
Apple, bitter pit	Long associated with low fruit calcium, with other factors involved [4]	Not transferable by itself
Tomato, blossom-end rot	Calcium shortage in distal tissue, with stress and water relations implicated [10, 31]	Different organ and water supply
Sweet cherry, quality	Calcium physiology and spray effects reviewed; benefit is not universal [32]	A reminder that sprays can disappoint
Peach, softening and browning	Calcium treatment altered wall properties and browning in experiments [33]	Postharvest application there; transfer unproven
Mango, internal breakdown including spongy tissue	Low flesh calcium is sometimes discussed among several contributing factors	Cause debated; no clean test found

Note: The mango entry is the authors' reading of the literature we could cite with confidence; it is not a finding.

For Banganapalli specifically, the position is simple to state. We found no cultivar-specific study of pre-harvest calcium sprays that we could cite with confidence, and the extension advice that circulates for the cultivar appears to be extrapolated from mango in general or from other fruit. That does not mean that sprays do not work on Banganapalli. It means that the case has to be built from mechanism and from related fruit, and that anyone who claims a particular size of effect for this cultivar is claiming more than the cited literature supports.

Internal breakdown disorders of mango, of which spongy tissue is a well-known example in some cultivars, are sometimes discussed in relation to low flesh calcium among several possible causes. As we understand the literature, the causes are

not settled, spongy tissue has been described mainly in cultivars other than Banganapalli, and a calcium spray cannot be assumed to prevent it. Growers often ask about it, and the honest answer is that the question is open.

3. Materials and Methods

3.1 Scope and Question

The review asks a question in two parts: is it plausible that pre-harvest calcium sprays improve firmness and extend the shelf life of Banganapalli mango, and how much weight can the existing evidence carry? The question was split into the sub-questions that a trial would have to answer: how calcium reaches the fruit, what it does in the wall, how the formulation and timing of a spray alter uptake, what injury or residue a spray may cause, and how firmness and shelf life ought to be measured and replicated in an orchard. None of these steps is difficult, but each is easy to skip.

3.2 Literature Assembly

The review draws on peer-reviewed work in four areas: calcium transport and physiology in fruit; the cell wall and ripening; foliar and fruit-surface uptake of nutrient salts; and disorders and sprays in apple, tomato, cherry, peach and mango. Sources were chosen for relevance and clarity of method, and work on other fruit is used for what it teaches about mechanism and limits, not as evidence of effects in mango.

We did not run a formal systematic search and we do not claim one. This is a narrative synthesis in the sense described in guidance on such reviews [35, 36], and the choice of sources reflects the authors' judgement; it is a better guide to what a good trial should contain than to the size of any effect.

3.3 Appraisal Framework

To judge how far a report of benefit can be trusted, we used a short framework. Is the unit of replication the tree or the fruit, and does the analysis match [37]? Is the study large enough and repeated across seasons, given what is known about the unreliability of small studies [38]? Is calcium actually measured in the fruit [2], and is firmness measured in a way that can be repeated [39]? Table 3 lists the features we looked for. It is a habit worth keeping even when the answer is expected.

Table 3. What a mango calcium-spray trial should report, and why.

Feature	Why it matters	What to record
Unit of replication	Fruit from one tree are not independent [37]	Trees as replicates, blocked by size and crop load
Cultivar and tree	Fruit calcium differs among cultivars and trees [1, 6]	Cultivar, age, rootstock, canopy
Spray timing	Receptivity changes with fruit development [5]	Days after fruit set, number of sprays
Formulation	Salts differ in uptake and injury [8, 27]	Calcium source, dose as calcium, surfactant, volume
Tissue calcium	Shows whether uptake occurred [2]	Flesh calcium at harvest, sampling position
Firmness method	Instrument and site change the number [39]	Device, probe, readings per fruit
Ripening conditions	Temperature and ethylene drive softening [24, 25]	Storage temperature, humidity, end point
Seasons	Single-season results can mislead [38]	Two or more seasons, same design

Note: The list reflects the methodological literature cited in the text and is not drawn from any single study.

4. Results

4.1 What Calcium Can and Cannot Do for Firmness

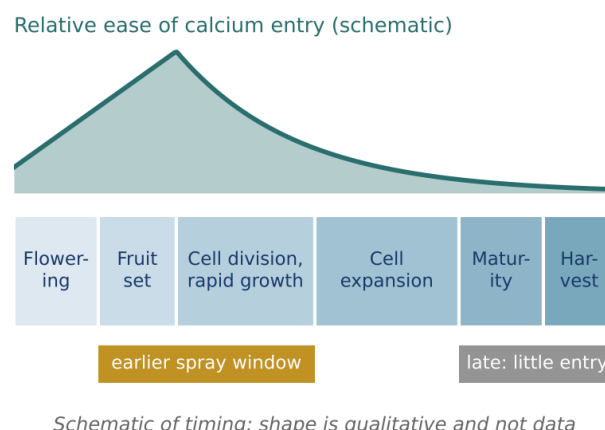
The mechanistic literature supports a narrow but real claim. Calcium cross-links de-esterified pectin and so strengthens the wall and the middle lamella [13, 14, 15], and wall disassembly is central to softening [18, 19]. If a spray raises calcium in the wall of the flesh, softening should be somewhat slower. That is where the support ends. None of the reviewed mechanistic work shows that a spray applied to mango in the orchard raises wall-bound calcium by an amount that changes softening, and none can, because that is an empirical question that belongs to trials.

Firmness is also not a single property. Instruments differ in what they measure, the site on the fruit changes the reading, and fruit-to-fruit variation within a tree is large [39]. Shelf life is a still more composite outcome, set by softening, water loss, skin condition and decay together, and the cuticle contributes to several of these [28, 29]. Small differences of this kind matter to a trader, because fruit are sold by the consignment and not by the best specimen.

4.2 When a Spray Can Matter

Timing is the most consistent theme in the physiology. Because xylem delivery to the fruit is greatest early and falls in relative terms as the

fruit enlarge [5, 6], sprays applied early in fruit growth address a fruit that is still receiving calcium and is still dividing and expanding cells. Sprays applied late meet a larger fruit that takes up little, with less time for calcium to be built into the wall. Figure 2 sketches the idea as a timeline of fruit development; it is a schematic of timing, not a plot of measurements.



Schematic of timing; shape is qualitative and not data

Figure 2. Fruit development and the window in which a spray can matter (schematic of timing, not data).

4.3 Formulation and Uptake

Calcium chloride and calcium nitrate are the salts most often mentioned in advisory material, and they differ in how readily they absorb moisture, how they behave on the surface and how likely they are to cause scorch [8, 27]. Chelated products are marketed on the basis of better uptake, but we know of no independent mango comparison that we could cite. The dose should be stated as calcium, not as product, because two products of the same weight can deliver quite different amounts of calcium.

Uptake itself is the step we should be least ready to take for granted. The polar pathways through the cuticle admit ions slowly [7, 26], humidity and drying time affect how long the deposit remains available [27], and the fate of foliar-applied nutrients, including whether they move to where they are needed, is poorly resolved [8]. A trial that reports a firmness benefit without measuring calcium in the flesh cannot say whether the spray acted through calcium at all, or through some effect of the formulation, of the surfactant, or of the wetting of the surface. A grower reading a trial report needs the answer to a plain question: would this have worked in my orchard?

4.4 Quality of the Evidence

The designs we would look for in a mango spray trial are listed in Table 3, and the common weaknesses of orchard experiments are well

known. Fruit from the same tree are not independent observations, and treating them as if they were inflates the apparent precision [37]. Small studies in any field produce unstable estimates and tend to overstate effects when they reach significance [38]. Mango crop load also varies from year to year, so a result from a single season may reflect that year as much as the spray. The point is not that a trial is poor, only that its result travels less far than its abstract suggests. A gain that vanishes when the second season is added was probably never a gain.

Put plainly, the literature supports only a cautious statement. A pre-harvest calcium spray is mechanistically plausible as a way of slowing softening in mango, sits within a well-developed but mixed literature in other fruit, and has not, to our knowledge, been established as beneficial for Banganapalli with evidence we can cite. The size of any effect is unknown, and it is probably modest and conditional on timing, formulation, season and storage. That is a modest claim, and it is the one the literature will currently bear.

4.5 Reading a Claim of Benefit

A reader meeting a claim that calcium sprays improved the firmness or shelf life of mango can ask a short sequence of questions (Figure 3). Did the spray reach the fruit at a stage when uptake is possible? Was calcium in the flesh measured, to show that uptake occurred? Did a wall effect follow, and was firmness measured by a repeatable method [39]? Was shelf life defined, and was it measured under ripening conditions that match commercial practice? A report that answers none of these should be read as an observation, not as evidence of effect.

5. Discussion

5.1 Interpretation and Practical Reading

The main finding of this review is a conditional one. A pre-harvest calcium spray is most likely to help where the fruit are short of calcium, where the spray is applied while the fruit can still take it up, and where the formulation actually delivers calcium to the flesh. It is least likely to help where the fruit already have enough calcium or where the spray comes too late. The question for a grower is therefore not whether calcium works, but whether the fruit in this orchard are short of it and whether this programme will deliver it. Nothing in this reading argues against spraying calcium; it argues for measuring what the spray achieves.

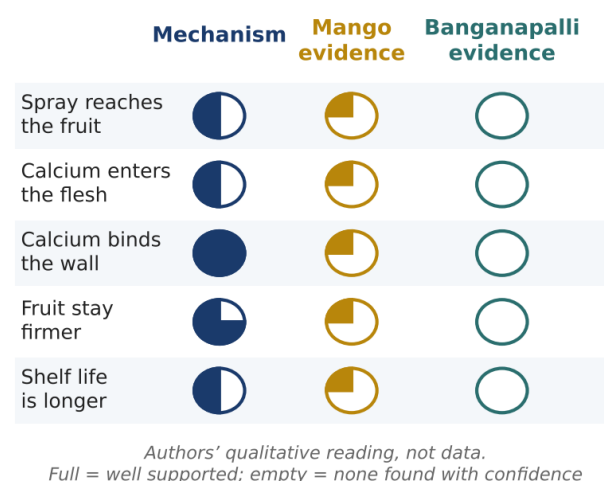


Figure 3. Links in the chain from spray to shelf life, rated qualitatively by the authors (not data).

5.2 Limitations

This is a narrative review and shares the limitations of that form. The selection of sources reflects judgement, no formal search or quality scoring was done, and the review does not quote numerical results from individual mango trials, because these could not be checked against the primary reports for this article. A reader who needs an effect size should consult the original studies directly, applying the appraisal questions above, or wait for a formal systematic review.

The review also draws heavily on evidence from other fruit and on general plant physiology, which are imperfect proxies for Banganapalli. We have used them to frame hypotheses, and the conclusions should be read in that light. Reviews are more useful when they say where the evidence stops than when they smooth it over.

5.3 Implications for Trial Design and Practice

A trial that could settle the question would use trees, blocked by size, vigour and crop load, as the units of replication [37]. It would state the calcium source, the dose as calcium, the volume, the surfactant and the timing in days after fruit set, and it would include an unsprayed control and, ideally, a water-only spray. It would measure calcium in the flesh at harvest, assess firmness with a repeatable method [39], hold the fruit under defined ripening conditions, and record skin injury and deposit. It would be repeated over at least two seasons. These points apply with equal force to any pre-harvest treatment promoted for keeping quality, not only to calcium.

5.4 Directions for Future Work

Three needs stand out. First, replicated trials on Banganapalli that report timing, dose, tissue

calcium, firmness method and storage conditions, over more than one season. Second, a comparison of the commonly sold formulations under the same conditions, with injury and deposit recorded. Third, a formal systematic review of calcium sprays in mango, with a transparent search and appraisal, to replace the narrative reading offered here [35].

6. Conclusion

Calcium is a sound candidate for slowing softening in mango, because it is part of what holds the wall together. The evidence, as we can responsibly summarise it, does not yet establish how large the effect of a pre-harvest spray is on Banganapalli, or whether it is large enough to matter commercially. What the literature does show is when a spray should work best, why uptake is the weak link, and what a fair trial would contain. Readers should treat claims of large gains with caution until they meet those standards.

For the practitioner, the message is practical rather than discouraging: calcium can be tried early, at a stated dose, on a few recorded trees, with an eye on injury as well as firmness. For the researcher, the opportunity is a set of well-designed orchard trials on this cultivar that measure what the spray delivers to the flesh, and so turn a plausible idea into a measured result.

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9. Conflict of Interest

The authors declare no conflict of interest.

10. Author Contributions

A.D. conceived the review and wrote the sections on calcium physiology and fruit disorders. E.P. wrote the sections on cell wall biochemistry and ripening. W.W. wrote the sections on foliar uptake, trial design and appraisal. All authors revised the manuscript and approved the final version.

11. Ethics Statement

This is a review of published literature. No human participants or animals were involved and no ethical approval was required.

12. Data Availability

No new data were generated. All sources are cited in the reference list.

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