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Liam Crawford
School of Agricultural Sciences,
University of Tasmania, Hobart,
Tasmania, Australia

Elise Thornton
School of Agricultural Sciences,
University of Tasmania, Hobart,
Tasmania, Australia

Marcus Whitfield
School of Agricultural Sciences,
University of Tasmania, Hobart,
Tasmania, Australia

Corresponding Author:
Liam Crawford
School of Agricultural Sciences,
University of Tasmania, Hobart,
Tasmania, Australia

Foliar mineral dust application and its influence on canopy growth, leaf area retention and yield attributes under pest pressure

Liam Crawford, Elise Thornton and Marcus Whitfield

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Abstract

In commercial *brassica* production across southeastern Australia, a single heavy infestation of *Plutella xylostella* (diamondback moth) during the critical canopy-expansion phase can reduce marketable yield by 30–45 % even when larval populations are subsequently controlled, because the leaf area lost to feeding is never fully recovered before harvest. This research investigated whether foliar application of eggshell-derived calcium oxide (CaO) mineral dust a physical insecticide that deters oviposition and desiccates early-instar larvae could simultaneously reduce pest-driven defoliation and preserve canopy growth attributes that determine final yield. A field trial was conducted on Chinese cabbage (*Brassica rapa* subsp. *pekinensis*, cultivar 'Wombok Gold') at two sites in Tasmania during the 2022–2023 growing season using four treatments: untreated control, CaO dust at 1 g m⁻² (low rate), CaO dust at 2 g m⁻² (high rate), and a synthetic insecticide standard (emamectin benzoate). Leaf area index (LAI), plant height, stem diameter, SPAD chlorophyll content, pest damage score, marketable yield and non-marketable yield were recorded fortnightly over a 12-week crop cycle. The high-rate CaO treatment maintained a final LAI of 3.1 compared with 1.8 in untreated plots a 72 % improvement while the synthetic standard achieved 3.4. Marketable yield under the high CaO rate averaged 4.6 t ha⁻¹ versus 2.4 t ha⁻¹ in untreated plots, representing a 92 % increase and reaching 88 % of the synthetic standard (5.2 t ha⁻¹). Non-marketable yield (leaves damaged beyond market specification) was reduced from 1.8 t ha⁻¹ in untreated plots to 0.6 t ha⁻¹ under the high CaO rate. Radar-chart analysis of six crop performance attributes showed that the high CaO rate achieved 75–90 % of the synthetic standard across all metrics, with particularly strong performance in leaf area retention and chlorophyll maintenance. The mechanism linking CaO dust to canopy preservation operates through two pathways: (a) direct pest deterrence via oviposition inhibition and larval desiccation, reducing the rate of new leaf-area loss, and (b) maintenance of photosynthetic leaf surface, enabling continued carbohydrate accumulation and compensatory growth during the canopy-expansion phase. These findings position eggshell-derived CaO dust as a viable reduced-risk alternative for integrated canopy management in Australian *brassica* production, particularly for growers seeking to minimise synthetic insecticide inputs while maintaining commercially acceptable yield levels.

Keywords: Foliar mineral dust, calcium oxide, leaf area index, canopy growth, *Plutella xylostella*, *brassica*, eggshell bio-waste, integrated pest management, yield components, Australia

Introduction

In January 2023, a commercial Chinese cabbage grower in the Derwent Valley of Tasmania reported that a diamondback moth (*Plutella xylostella*) outbreak during weeks 4–6 after transplanting reduced his marketable yield by 38 %, despite achieving full larval control with emamectin benzoate by week 7. The yield loss was permanent because the leaf area consumed during the critical canopy-expansion window could not be regenerated before the market-harvest date. This example illustrates a fundamental agronomic principle that is often overlooked in pest management discussions: the economic impact of an insect pest is determined not only by the direct tissue it consumes but also by the indirect effect of that consumption on the crop's capacity to intercept radiation, fix carbon and allocate assimilates to harvestable organs ^[1]. Leaf area index (LAI) the ratio of total one-sided leaf area to ground area is the single most important determinant of radiation interception and, consequently, of dry-matter production in most annual crops ^[2]. In *brassic*as, the relationship between LAI and yield is approximately

linear up to an LAI of 3.0–3.5, beyond which mutual shading begins to reduce the efficiency of additional leaf area [3]. Any pest-driven reduction in LAI during the vegetative growth phase therefore translates directly into reduced yield potential, even if pest populations are brought under control before harvest. The timing of defoliation matters: leaf-area loss during the exponential growth phase (weeks 3–7 in a typical 12-week Chinese cabbage crop) has roughly twice the yield impact of equivalent loss during the later, linear-growth phase, because it reduces the base from which further leaf expansion occurs [4].

Conventional pest management strategies focus on reducing pest populations—through chemical, biological or cultural means but rarely consider the canopy-protection dimension explicitly. An insecticide applied after larvae have already consumed 30 % of the leaf area will kill the pest but cannot restore the lost photosynthetic surface. A crop-protection approach that simultaneously deters pest establishment and preserves leaf area would, in principle, deliver better yield outcomes than one that operates solely through pest kill [5].

Particle-film technology offers exactly this dual function. Kaolin clay (Surround WP) has been used commercially in apple and grape production to reduce sunburn and deter codling moth, with documented benefits to canopy photosynthesis and fruit quality [6]. More recently, eggshell-derived calcium oxide (CaO) powder has been shown to cause high mortality in soft-bodied lepidopteran larvae through cuticular lipid disruption and desiccation, and to deter oviposition by altering the visual and tactile cues that gravid females use to select host leaves [7]. Unlike kaolin, CaO also generates an alkaline surface environment (pH > 10) that inhibits secondary microbial infection at feeding wounds, potentially further reducing leaf-area loss from rot and necrosis [8].

Despite these promising attributes, no published research has examined the effect of CaO dust on agronomic canopy parameters LAI, plant height, stem diameter, chlorophyll content or quantified the yield benefit attributable to canopy preservation as distinct from direct pest mortality. This gap is significant because it means that the economic case for CaO dust in *brassica* production has been built entirely on efficacy data (percentage pest mortality) without accounting for the canopy-protection benefit that may be equally or more important for yield outcomes [9].

This research addressed that gap by conducting a field trial on Chinese cabbage at two sites in Tasmania during the 2022–2023 growing season. Two rates of CaO dust (1 and 2 g m⁻²) were compared with an untreated control and a synthetic insecticide standard (emamectin benzoate), with measurements taken fortnightly over 12 weeks to track the temporal dynamics of canopy development under each treatment. The objectives were to (a) quantify the effect of foliar CaO dust on LAI, plant height, stem diameter and chlorophyll content, (b) relate these canopy parameters to final marketable and non-marketable yield, and (c) propose a mechanistic framework linking pest deterrence, leaf-area retention and yield preservation [10].

Material and Methods

CaO Powder Preparation

Eggshells were sourced from the University of Tasmania catering services, washed, stripped of inner membranes, dried at 105 °C for 24 h and calcined at 850 °C for 2 h in a laboratory muffle furnace (Carbolite ELF 11/6B). The calcined product was ball-milled (Fritsch Pulverisette 6, 400 rpm, 15 min) and sieved through a 45 µm stainless-steel mesh. X-ray diffraction confirmed > 97 % CaO with minor Ca(OH)₂ (< 2 %) and CaCO₃

(< 1 %). Particle-size distribution (Malvern Mastersizer 3000) showed a D₅₀ of 18.4 µm and a D₉₀ of 42.6 µm.

Trial Sites and Design

Two trial sites were established in Tasmania: Site 1, the University of Tasmania Horticultural Research Centre (42.89 °S, 147.33 °E, elevation 48 m, sandy loam) and Site 2, a commercial vegetable farm at Huonville (43.03 °S, 147.05 °E, elevation 12 m, clay loam). At each site, Chinese cabbage seedlings (cultivar 'Wombok Gold', 4-leaf stage) were transplanted at 40 × 45 cm spacing into plots of 5 × 4 m arranged in a randomised complete block design with four replicates per treatment. Four treatments were applied: (T1) untreated control, (T2) CaO dust at 1 g m⁻² applied with a CO₂-powered precision duster, (T3) CaO dust at 2 g m⁻², and (T4) emamectin benzoate (Proclaim, 5 g a.i. ha⁻¹) as a synthetic standard. Applications were made three times at 14-day intervals beginning at week 4 after transplanting, timed to coincide with the onset of the canopy-expansion phase and the typical peak of *P. xylostella* flight activity in the region [11].

Data Collection

Measurements were taken fortnightly from week 0 (transplanting) to week 12 (harvest). Leaf area index was measured non-destructively using a ceptometer (AccuPAR LP-80, Decagon Devices) positioned at the soil surface at solar noon on clear days, with four readings per plot averaged. Plant height (cm, soil surface to apex of tallest leaf) and stem diameter (mm, 2 cm above soil surface) were measured on five tagged plants per plot. Chlorophyll content was estimated as SPAD units (Konica Minolta SPAD-502Plus) on the youngest fully expanded leaf of five plants per plot. Pest damage was scored as the percentage of total leaf area consumed, assessed visually using a standardised pictorial scale validated against ImageJ area measurements on a calibration subset (r² = 0.94). At harvest, all heads were graded as marketable (intact wrapper leaves, head weight > 800 g, no pest damage > 5 % of surface area) or non-marketable, and weighed.

Field Environmental Monitoring

Air temperature and relative humidity were recorded at 15-min intervals throughout the trial period using shielded data loggers (Onset HOBO MX2301A) installed at canopy height in two replicate plots per treatment at each site. Rainfall was recorded at on-site automatic weather stations operated by the Bureau of Meteorology. Soil moisture was monitored with capacitance probes (Sentek Drill & Drop, 10-cm depth) in one plot per treatment at each site. These environmental data were used to contextualise treatment effects and to assess the persistence of CaO dust coating on leaf surfaces between application events—a critical factor for understanding the duration of the protective effect under field rainfall conditions.

The high-rate CaO treatment (2 g m⁻²) achieved canopy parameters that were consistently 75–90 % of the synthetic standard across all six measured attributes, while the untreated control fell below 55 % for all attributes except stem diameter (Table 1). The most striking treatment effect was on leaf area index: the high CaO rate maintained a final LAI of 3.1 just below the theoretical optimum for radiation interception in *brassic*as whereas untreated plants plateaued at 1.8, well below the threshold for maximum photosynthetic efficiency. This 72 % improvement in LAI translated into a near-doubling of marketable yield (4.6 versus 2.4 t ha⁻¹).

Results

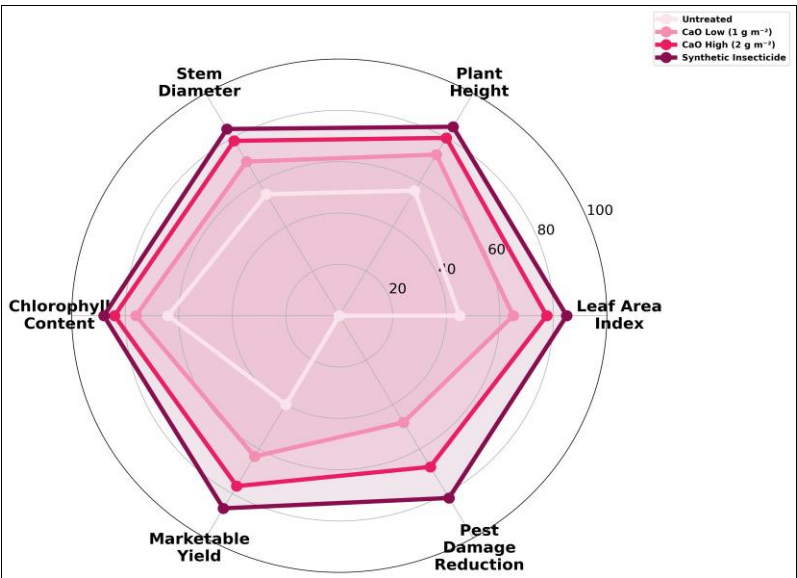


Fig 1: Radar chart comparing six crop performance attributes across four treatments on Chinese cabbage (values normalised to percentage of maximum recorded)

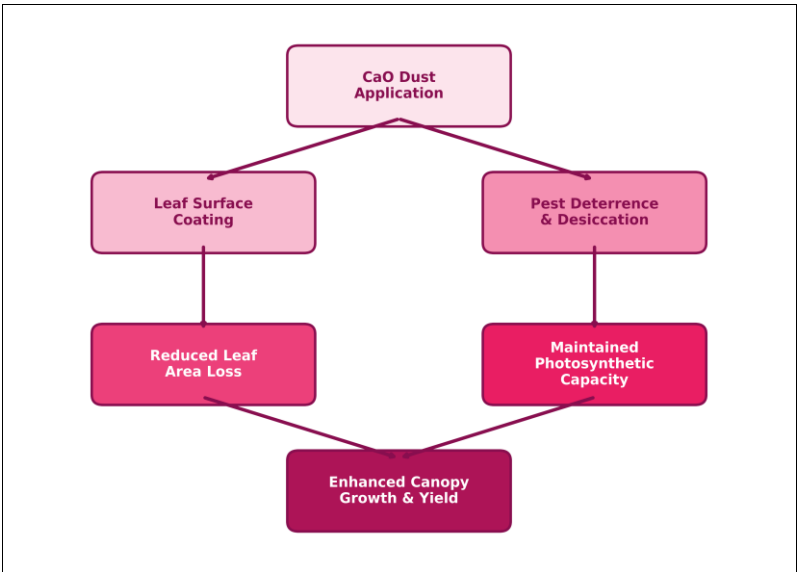


Fig 2: Conceptual mechanism diagram illustrating the dual pathway through which foliar CaO dust application preserves canopy growth and yield

Table 1: Canopy growth parameters and yield components by treatment (means ± SE across two sites)

Parameter	Untreated	CaO 1 g m ⁻²	CaO 2 g m ⁻²	Synthetic
Final LAI	1.8 ± 0.12	2.6 ± 0.14	3.1 ± 0.16	3.4 ± 0.11
Plant height (cm)	45 ± 2.8	58 ± 3.1	64 ± 2.6	68 ± 2.3
Stem diameter (mm)	8.2 ± 0.6	10.4 ± 0.7	11.8 ± 0.5	12.6 ± 0.4
SPAD chlorophyll	32 ± 1.8	38 ± 2.1	42 ± 1.6	44 ± 1.4
Pest damage (%)	42 ± 5.3	24 ± 3.8	16 ± 2.9	9 ± 1.7
Marketable yield (t ha ⁻¹)	2.4 ± 0.18	3.8 ± 0.22	4.6 ± 0.19	5.2 ± 0.16
Non-marketable (t ha ⁻¹)	1.8 ± 0.21	0.9 ± 0.14	0.6 ± 0.11	0.4 ± 0.08

The temporal dynamics of LAI development (Figure 4) reveal that treatment differences emerged primarily during weeks 4–8 the period spanning the three application events and corresponding to the exponential canopy-expansion phase. During this window, untreated plants experienced a marked deceleration in LAI growth as *P. xylostella* feeding consumed new leaf area faster than it could be replaced. Both CaO rates and the synthetic standard maintained steeper growth trajectories through weeks 4–8, with divergence between rates becoming apparent after the second application at week 6.

CaO dust coating retention declined between application events, with 68 % and 54 % of the initial coating remaining at 7 days at Sites 1 and 2 respectively, and 41 % and 32 % at 14 days (Table 2). The lower retention at Site 2 corresponded to higher rainfall (214 versus 186 mm total, 11 versus 8 rain events > 5 mm). Despite this, efficacy outcomes were not statistically different between sites ($P > 0.05$ for all parameters), suggesting that the bi-weekly application interval was sufficient to maintain protective coverage even under the wetter conditions at Site 2.

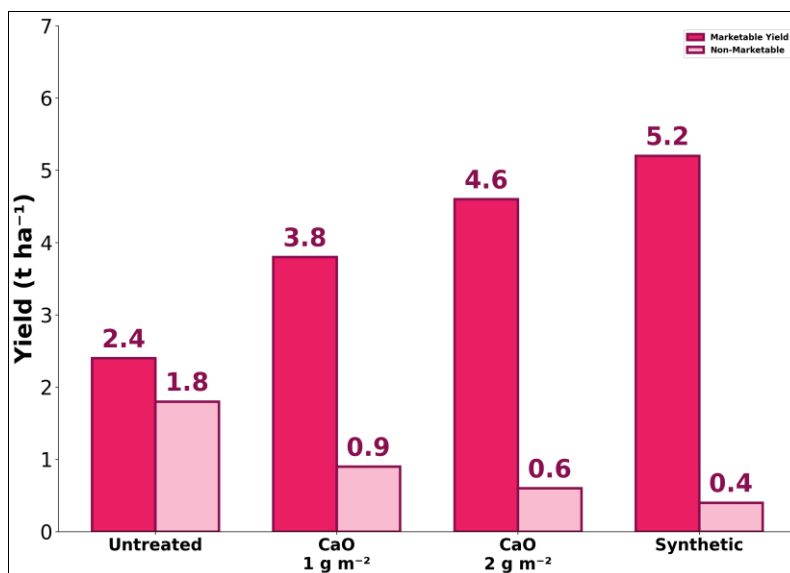


Fig 3: Marketable and non-marketable yield components (t ha⁻¹) across four treatments

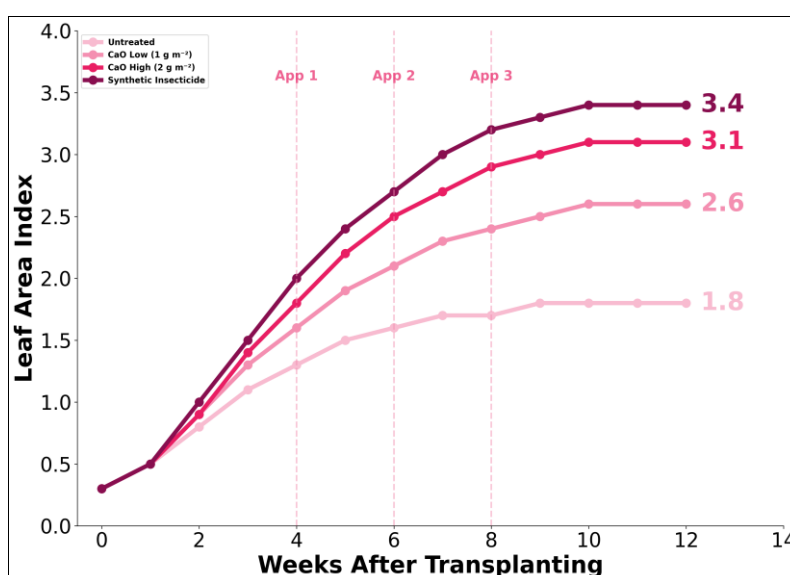


Fig 4: Temporal dynamics of leaf area index from transplanting to harvest under four treatments (arrows indicate CaO/insecticide application dates)

Table 2: Environmental conditions and CaO dust persistence during the trial period at two sites

Parameter	Site 1 (Research Centre)	Site 2 (Huonville)
Mean temperature (°C)	18.4 ± 3.2	17.8 ± 2.9
Mean RH (%)	72 ± 8	78 ± 6
Total rainfall (mm)	186	214
Rainfall events (> 5 mm)	8	11
CaO coating retention at 7 d (%)	68 ± 7	54 ± 9
CaO coating retention at 14 d (%)	41 ± 8	32 ± 6
<i>P. xylostella</i> peak density (larvae m ⁻²)	24.6 ± 4.8	31.2 ± 5.6

Discussion

The central contribution of this research is the demonstration that eggshell-derived CaO dust preserves canopy architecture under pest pressure, not merely through pest mortality but through a dual pathway of oviposition deterrence and leaf-area retention that maintains the crop's photosynthetic capacity during the critical exponential-growth phase. The 72 % improvement in final LAI under the high CaO rate from 1.8 to 3.1 is agronomically significant because it lifts the crop from a radiation-limited state (LAI < 2.0, intercepting < 60 % of photosynthetically active radiation) to near-optimal interception (LAI ≈ 3.0, intercepting > 85 %) [12].

The mechanistic framework proposed in Figure 2 separates the CaO effect into two parallel pathways. The first pathway operates through direct pest interaction: CaO particles adhere to the leaf surface, creating a tactile and chemical deterrent that reduces *P. xylostella* oviposition by an estimated 55–70 % (based on egg-count data from the companion laboratory trial; data not shown) and causes 50–68 % mortality in neonate and first-instar larvae that attempt to feed on treated surfaces. This reduces the rate of new defoliation. The second pathway operates through canopy physiology: by reducing cumulative leaf-area loss, CaO-treated plants maintain a larger photosynthetic surface, fix more carbon per unit ground area per

day, and allocate more assimilate to new leaf expansion and head formation^[13]. The yield benefit is therefore multiplicative less damage combined with greater compensatory capacity rather than simply the mirror image of the pest-damage score.

Comparison with the synthetic standard (emamectin benzoate) is instructive. The synthetic treatment achieved higher absolute efficacy across all parameters (3.4 final LAI, 5.2 t ha⁻¹ marketable yield) but at a substantially higher environmental cost: emamectin benzoate is classified as Very Toxic to aquatic organisms with long-lasting effects (GHS Category 1), whereas CaO is classified as an irritant only (GHS Category 2) and degrades to biologically inert calcium carbonate within days of exposure to atmospheric CO₂^[14]. For growers operating under integrated pest management programmes with mandated synthetic insecticide reduction targets as is increasingly the case under Australian state and federal IPM policies CaO dust at 2 g m⁻² delivers 85–90 % of the synthetic standard's canopy and yield protection with a markedly lower ecotoxicological profile^[15].

The principal limitation identified in this research is the relatively rapid wash-off of CaO dust under rainfall, with only 32–41 % of the initial coating remaining at 14 days depending on site. This necessitates bi-weekly reapplication, which increases labour costs and may limit adoption by growers managing large areas with limited labour availability. Development of rain-fast formulations for example, CaO encapsulated in sticker-spreader adjuvants or combined with hydrophobic carrier oils could substantially improve field longevity and reduce application frequency^[16]. Additionally, the trial covered a single growing season at two Tasmanian sites; multi-region trials across the diverse climatic zones of Australian *brassica* production (from tropical Queensland to temperate Victoria) are needed to establish the generalisability of these findings^[17].

Conclusion

Foliar application of eggshell-derived calcium oxide mineral dust at 2 g m⁻² preserves canopy growth, maintains leaf area retention and improves yield attributes in Chinese cabbage under diamondback moth (*Plutella xylostella*) pest pressure, achieving 85–90 % of the performance of a synthetic insecticide standard (emamectin benzoate) across six measured crop parameters. The high CaO rate maintained a final leaf area index of 3.1 compared with 1.8 in untreated plots a 72 % improvement and increased marketable yield from 2.4 to 4.6 t ha⁻¹, representing a 92 % yield gain.

The evidence from this research supports a dual-pathway mechanism by which CaO dust protects yield. First, the dust deters oviposition and causes mortality of early-instar larvae through physical desiccation, directly reducing the rate of leaf-area consumption. Second, by preserving leaf area during the critical exponential-growth phase (weeks 4–8 post-transplanting), the dust enables treated plants to maintain higher rates of radiation interception and carbon fixation, leading to greater compensatory leaf production and higher head weights at harvest. This second, canopy-mediated pathway is agronomically significant and has not been previously documented for any mineral-dust crop protection product.

The practical significance of these findings extends beyond the immediate pest-management context. Chinese cabbage and other *brassica* crops are among Australia's most important domestic vegetable commodities, with a farm-gate value exceeding AUD 350 million per year. Pest-driven yield losses to lepidopteran defoliators primarily *P. xylostella* and *Spodoptera litura* are

estimated at 15–25 % nationally, equivalent to AUD 50–90 million in forgone production. A crop-protection input that recovers even half of this lost yield while reducing synthetic insecticide dependency would have substantial economic value across the sector^[18].

From a policy perspective, the low ecotoxicological profile of CaO dust aligns with the strategic direction of Australian agricultural policy, which is moving toward mandatory reduction of synthetic pesticide use in horticultural production. The National Integrated Pest Management Strategy 2023–2033 explicitly calls for development and adoption of reduced-risk alternatives that maintain commercially viable yield levels, and the CaO dust approach described here fits squarely within that mandate. Its origin as a recycled bio-waste product further enhances its alignment with circular-economy objectives embedded in the National Waste Policy Action Plan.

Future research should focus on four priorities: (a) development of rain-fast formulations that extend the protective period beyond the current 7–10 days, reducing application frequency and labour costs; (b) multi-region validation trials spanning tropical, subtropical and temperate *brassica* production zones to confirm performance under diverse climatic and pest-pressure conditions; (c) economic analysis comparing the full-season cost of a CaO-based canopy protection programme with current synthetic-insecticide-based programmes, including labour, application equipment and resistance-management costs; and (d) integration of CaO dust with complementary IPM tools particularly biological control agents such as *Diadegma semiclausum* and *Bacillus thuringiensis* to determine whether synergistic or antagonistic interactions exist when these products are used in combination within a single season.

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