

Efficacy of Neem-Based Formulations Against Whitefly in Cotton Under Field Conditions

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ABSTRACT

Neem-based products are among the most widely recommended botanical options against the whitefly Bemisia tabaci in cotton, a pest that damages the crop by feeding, by fouling lint with honeydew and by carrying viruses, and that has repeatedly outrun synthetic insecticides. This mini review asks how far the case for neem rests on field evidence, as opposed to laboratory bioassays. It draws on published work on azadirachtin and related compounds, on whitefly biology and resistance, on natural enemies and on the design of efficacy trials, and it reports no new data. Neem acts mainly by deterring feeding and egg laying and by disrupting development of immature stages, so it is slow and works best against nymphs. Field performance is variable. The active content of crude products differs between batches, azadirachtin breaks down quickly in sunlight, undersides of leaves in a dense canopy are hard to wet, and immigration from neighbouring crops can mask a real effect. Laboratory results therefore tend to overstate what a farmer will see. Neem is gentler on many natural enemies than broad-spectrum chemistry but is not free of non-target effects. The review concludes that neem is best treated as a component of integrated management, and it lists what a trial must report before a field claim can be trusted.

Keywords: Neem; Azadirachtin; Bemisia tabaci; Cotton; Botanical insecticide; Field efficacy; Narrative review

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1. Introduction

Few pests have tested cotton growers as persistently as the whitefly *Bemisia tabaci*. It takes sap from the underside of the leaf, covers the plant with honeydew on which sooty moulds grow, and carries viruses, among them the begomoviruses behind cotton leaf curl disease [1, 2, 3]. In several cotton regions the disease has become one of the main threats to the crop [4], and insect pests in general carry a heavy economic cost for farming [5].

Chemical control has not held the line. Resistance to organophosphates, pyrethroids and, more recently, neonicotinoids has been reported in whitefly populations across cotton-growing countries [6, 7, 8, 9], and the mechanisms are not exotic: enhanced detoxification by cytochrome P450 enzymes is enough to blunt a modern insecticide [10]. It is little surprise that growers and advisers look to alternatives, and neem, the seed oil and extracts of *Azadirachta indica*, is usually the first one named [11, 12]. Whether it deserves that position is the question here.

The case for neem is easy to make on paper. Azadirachtin, its best-known active compound, disrupts feeding and development in many insects, the tree grows widely in South Asia, and products are available as home-made extracts or as standardised concentrates [13, 14]. The case is harder to make in a cotton field in July. This mini review asks how much of what is claimed for neem against whitefly survives the move from laboratory to field, and why results differ so much from one report to the next. The aim is a fair account of what is known and what is merely repeated.

We write it as a narrative review of published work. It reports no new data, and where field evidence is thin we say so instead of quoting figures that we could not check against their sources. Throughout, the emphasis is on what a grower could realistically expect from a spray, and on how confidently that expectation can be carried from one field, season or whitefly population to another.

2. Literature Review

2.1 The Whitefly and Its Place in Cotton

Bemisia tabaci is now understood as a complex of cryptic species that look alike but differ in host range, insecticide susceptibility and ability to transmit viruses [15]. That matters for any efficacy claim, because a product tested on one member of the complex may not behave the same on another, and field populations in a single region can be mixtures. Resistance surveys on the Indian subcontinent, for example, have found differences in insecticide response between genetic groups [8].

Damage comes by three routes. Direct feeding weakens plants. Honeydew soils the lint and lowers its quality. Virus transmission can cause losses that no spray threshold based on counts would predict [1, 2]. A control method must therefore be judged against more than the number of insects on a leaf, since a small population carrying a virus can matter more than a large one that does not.

Management programmes that have worked well combine selective chemistry, cultural measures and the conservation of natural enemies, instead of relying on one product [16, 17]. In that setting neem is not a replacement for synthetic insecticide so much as a candidate for one slot in a programme, and it should be judged for the slot it is meant to fill. A product can look excellent on a leaf disc and unremarkable on a hectare.

2.2 What Neem Does to Insects

Neem seed contains a family of limonoids, of which azadirachtin is the most studied, along with oil and other compounds [12, 13]. Azadirachtin deters feeding and egg laying and, in immature insects, disturbs the hormonal control of moulting, so that nymphs fail to develop normally [18]. These actions are quite different from the quick nervous-system poisoning of most conventional insecticides, and they have a consequence that growers do not always expect: neem works slowly, and a spray may leave many insects alive for days even when it is doing its job [14].

Early work on the sweetpotato whitefly, a name then in common use for *B. tabaci*, reported effects of neem seed extract on oviposition and on immature stages [19]. The pattern fits the mode of action. Eggs, nymphs and adults are affected differently, and Figure 2 gives a qualitative reading of which action is likely to matter for which stage. The figure is our own summary and not a plot of measurements.

Neem acts on a pest that has been selected for decades to survive other chemistry, and it seems reasonable to ask whether resistance could develop. Selection experiments with the green peach aphid showed that resistance to azadirachtin could be raised in the laboratory, although the process was described as slow [20]. Whether whiteflies in cotton fields would respond in the same way has not been settled, and the multi-component nature of crude extracts is sometimes argued to slow resistance without much direct evidence for whitefly.

	Feeding deterrence	Moult and growth disruption	Egg-laying deterrence	Direct kill on contact
Egg	n/a	n/a	n/a	possible
Nymph	main role	main role	n/a	possible
Adult	possible	n/a	main role	minor

Authors' qualitative reading of the cited literature; not data

Figure 2. Qualitative reading of how neem acts on whitefly stages (authors' summary, not data).

2.3 Why Preparations Differ

Neem is not one product. Farmers use aqueous kernel extracts, cold-pressed oil emulsified with soap, and commercial concentrates sold on declared azadirachtin content (Table 1). The

azadirachtin content of seed varies with the tree, the region, the season and the way the seed is stored and extracted, and bioefficacy follows that variation [21]. A farmer who makes an extract at home is applying an unknown dose, and a researcher who reports only the weight of kernel used has told the reader very little.

Table 1. Common neem preparations and their main field concerns.

Preparation	Main attraction	Main field concern
Aqueous seed-kernel extract	Cheap; can be made on the farm	Active content unknown and variable; degrades quickly [14, 21]
Cold-pressed neem oil, emulsified	Easy to find; oil film may add a contact effect	Quality of emulsion varies; azadirachtin content varies [21]
Standardised azadirachtin concentrate	Declared active content; repeatable	Cost; short persistence on foliage [13, 14]
Neem with soap or surfactant	Better wetting of leaf surfaces	Compatibility must be checked; added effects on natural enemies [29]

Note: Qualitative comparison drawn from the cited literature. Active content is deliberately not given in numbers because it depends on the batch and the product.

Azadirachtin is also not a stable molecule in the field. It is sensitive to light and to the conditions of the spray tank and leaf surface, so that residues on foliage lose activity faster than many growers assume [13, 14]. Standardised formulations with stabilisers can narrow the gap, but they cost more, and the botanical-insecticide literature repeatedly points out that the practical constraints on botanicals, such as stability, supply and regulation, are as important as their bioactivity [22, 23, 24].

2.4 Natural Enemies and Other Non-Target Organisms

A large part of the appeal of neem is that it is considered gentler on beneficial insects than broad-spectrum sprays. Conservation of natural enemies has been shown to be a real contributor to whitefly control in cotton [25], so a product that spares them has value beyond its direct action on the pest. The qualifier is that gentler is not harmless. Neem seed oil has been shown to affect an egg parasitoid in laboratory work [26], and the wider literature on sublethal pesticide effects warns that survival after exposure says little about whether an insect forages, mates or reproduces normally [27, 28].

The sense that anything of plant origin is safe also deserves caution. A comparison of organic-certified and synthetic products on a predatory bug found that some of the certified

products had important side effects [29]. The study covered a range of products and the lesson carries over: selectivity has to be tested for each product, crop and natural enemy, not inferred from the label on the container. Whiteflies that are not touched by a spray do not stay untouched for long.

2.5 Resistance and the Insecticide Context

Neem is seldom applied to a field that has had no other chemistry. Whiteflies in cotton often arrive carrying resistance to the products that came before [7, 30], and a field sprayed repeatedly with broad-spectrum material may have lost much of its predator and parasitoid fauna, which changes how any later product performs. In an integrated programme developed in Arizona, careful sequencing of selective compounds and the protection of natural enemies were central to success [16]. A neem trial run in a field with a very different spray history cannot be read as if it were run in a clean one.

Sublethal stress from pesticides can also change pest populations in ways that do not appear in a simple mortality count [31]. This is a reason to measure more than kill: oviposition, nymph survival and the build-up of the next generation tell a fuller story than a count taken a few days after the spray.

3. Materials and Methods

3.1 Scope and Question

The review asks one question in two parts: how consistently do neem-based formulations suppress whitefly in cotton under field conditions, and what explains the differences reported between laboratory and field? We considered the biology of the pest, the chemistry and formulation of neem, the effects on natural enemies and the way field trials are designed and analysed. None of these steps is difficult, but each one is easy to skip.

3.2 Literature Assembly

We drew on peer-reviewed work in four areas: whitefly biology, damage and resistance; neem chemistry and mode of action; non-target and sublethal effects; and the methodology of efficacy trials. Sources were chosen for relevance, standing in the field and clarity of methods. Studies of other pests or other botanicals are used for what they teach about mechanism and limits, not as evidence of effect on whitefly in cotton.

We did not run a formal systematic search and we do not claim one. This is a narrative synthesis, and the choice of sources reflects the authors' judgement. The practical consequence is that the

review is a better guide to the structure of the evidence than to the size of any individual effect, and it avoids quoting figures from individual field trials that could not be verified against the primary papers.

3.3 Appraisal Framework

To judge how far a field report can be trusted we asked four questions. Was the product described well enough to be repeated, including its active content? Were applications and assessments described in a way that allows for coverage, timing and the life stage counted? Was the plot the unit of analysis, with real replication, instead of leaves or plants within a plot [32]? And were effects expressed against an untreated control with a recognised correction for natural change in the population [33, 34]? Table 2 lists the sources of variation that we looked for.

Table 2. Sources of variable field efficacy and what a trial should report.

Source of variation	How it acts	Report in a trial
Active content	Batch and storage change dose [21]	Azadirachtin content, product, age
Sunlight and weather	Breakdown shortens protection [14]	Time of day, rain, temperature
Spray coverage	Nymphs sit on leaf undersides [7]	Nozzle, volume, canopy stage
Timing and stage	Slow action favours immature stages [18, 19]	Stage counted, days after spray
Immigration	Adults arrive from nearby fields [25]	Plot size, buffers, neighbours
Insecticide history	Resistance and disrupted natural enemies [8, 30]	Prior sprays on the field
Assessment method	Counts are patchy and unit is often wrong [32, 33]	Sampling plan, replication

Note: The right-hand column is the authors' suggestion for reporting, not a requirement stated in any single cited paper.

4. Results

4.1 What the Evidence Looks Like

The literature on neem and whitefly is easiest to understand as three layers. At the bottom are laboratory bioassays on leaf discs or potted plants, where dose, coverage and exposure are controlled. Above them are greenhouse and small-plot studies, and at the top are trials and observations in working fields (Figure 1). Each step adds sources of variation, and the evidence becomes both more relevant to the grower and harder to interpret.

A general problem is that many botanical reports leave out the details needed to repeat them, such

as the concentration actually applied, the controls used, or the way a plant extract was prepared. A critical look at the botanical-insecticide literature concluded that there are many publications but limited useful data [35]. That judgement is not specific to neem, but neem studies are not exempt from it. This is why the same product can look excellent in one report and unremarkable in the next.

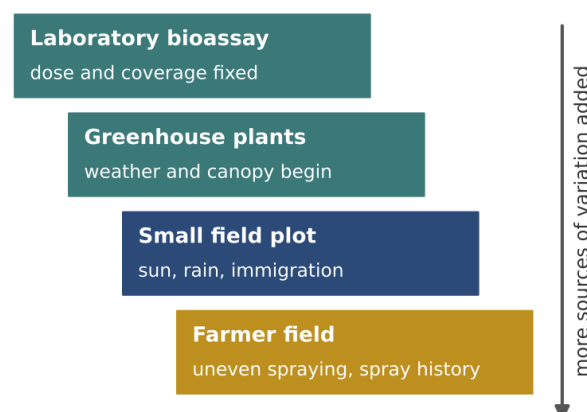


Figure 1. From bioassay to farm field: what each step adds (schematic, not data).

4.2 Laboratory Activity Is Real

It would be wrong to read the field difficulties as a sign that neem does not work. The mode of action is well characterised [13, 18], effects on whitefly oviposition and immature stages were reported early [19], and later reviews of botanicals have generally regarded azadirachtin as one of the better-supported plant-derived actives [14, 22]. In a bioassay, where each insect receives a known exposure to a fresh deposit, neem often looks very good.

The trouble is that a bioassay answers a narrower question than a grower asks. It asks what the compound does when it reaches the insect. The grower wants to know how often it reaches the insect at all. Between the two lie spray coverage, weathering and the timing of the application relative to the life cycle. Read this way, a null result from a small plot is not proof that the product does nothing.

4.3 Why the Field Gives Different Answers

Whitefly nymphs live on the underside of leaves, often deep in the canopy, and a spray that wets the upper surface does little for them. Reviews of insecticidal control of whitefly discuss coverage and application technique alongside the choice of product [7]. Neem deposits are also short-lived. If residue fades before the next generation of nymphs has developed, the population recovers

between sprays (Figure 3).

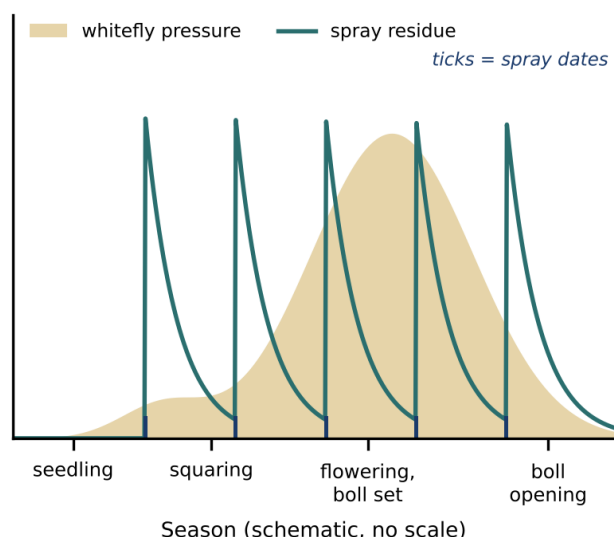


Figure 3. Schematic of a cotton season: spray residue fading while whitefly pressure shifts (not data).

Population movement is the second problem. Whitefly adults move in from neighbouring crops and weeds, and in cotton the contribution of immigration to local numbers can swamp a treatment effect in a small plot [25]. A plot trial may therefore underestimate a product that would work across a whole farm, or overstate one that happened to be placed next to a clean field. Because neem acts slowly and mainly on immature stages, it is particularly exposed to this problem: adults arriving after the spray lay eggs on foliage that has begun to lose its protection.

Cropping and cultural practice shape how any product performs, and sanitation, crop timing and the management of alternative hosts can lower the pressure before a spray is applied [17]. A neem programme run on top of poor cultural control is asked to do a job that no insecticide can do on its own. A saving that disappears once the extra sprays are counted is not a saving a grower would feel.

4.4 Non-Target Effects in the Field

The field is also where the selectivity question is truly answered. Natural enemies contribute substantially to whitefly suppression in well-managed cotton [25]. If neem spares them better than broad-spectrum sprays, the net result over a season may be better than a count of whitefly after one application would suggest. If it harms them, the gain can be lost. The literature offers examples of both kinds of finding for botanicals in general [26, 29], and for neem against whitefly in cotton we found little evidence from well-replicated field work that could settle the question either way.

4.5 Weak Points in the Reporting

Field reports on botanicals commonly share a set of weaknesses. Active content is not given, spray volumes are not stated, and counts are taken from leaves as if each were independent, which inflates precision [32]. Corrections for natural population change are sometimes omitted, or applied without comment [33, 34]. Positive results in small, flexible studies are more likely to be reported than null ones, and a field in which most published results are positive is not necessarily one in which most products work [36].

5. Discussion

5.1 Interpretation and Practical Reading

The main message of the review is that neem is a real tool whose field performance is variable and context-dependent. It is slow, it works best against immature stages and against egg laying, it needs good coverage of leaf undersides, and it fades quickly. Used well, as a component of a programme that also protects natural enemies and manages the crop environment, it can reasonably be expected to help. Used as a drop-in substitute for a knockdown insecticide, it is likely to disappoint. Nothing in this reading argues against using neem; it argues for knowing what it is being asked to do.

The second point concerns how results should be read. A laboratory result that shows high activity should be treated as evidence of potential, not of field performance. The same product may show a very different outcome in a field with a long history of intensive spraying, and this makes comparison between trials treacherous. Smallholder systems, where botanical products are most often promoted [37], add further variation in application quality and in the preparation of the product itself.

A third point is that the question of resistance has two sides. Neem is often described as unlikely to select for resistance, and the laboratory selection work on another pest suggests that it is at least slower than with single-site chemistry [20]. That is a reason for cautious optimism, not an assurance, and a programme that applies neem repeatedly at the same stage of the pest cycle invites exactly the selection pressure that rotation is supposed to avoid. These points apply with equal force to any botanical product, not only to neem.

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 effect sizes from individual field trials, because they could not be checked against the primary reports for this article. A reader who needs a figure should consult the original studies directly, applying the appraisal questions above, or wait for a formal systematic review that can handle differences between trials.

The review also leans on work from other pests and on general reviews of botanicals. Those sources illuminate mechanism, formulation and reporting, but they are imperfect proxies for whitefly in cotton, and conclusions about field efficacy should be read in that light. Reviews of this kind are more useful when they say where the evidence stops than when they smooth it over.

5.3 Implications for Trial Design

A trial that could settle the matter would state the product and its azadirachtin content, apply it with documented equipment and volume, and replicate at the plot level with a true untreated control. It would count more than one life stage, sample on a stated schedule, and record the days between spray and assessment [32, 33]. It would document neighbouring crops and spray history, and it would measure natural enemies alongside whitefly so that selectivity is tested in the same field [25, 27].

It would also test neem as part of a programme, for instance in rotation with selective compounds, since that is how it is likely to be used. Reporting results as estimates with the uncertainty visible, not as bare significance tests, would let growers and advisers weigh them for themselves.

5.4 Directions for Future Work

Three needs stand out. First, replicated field trials in cotton with standardised, well-described formulations and complete reporting. Second, work on neem within integrated programmes, including effects on natural enemies and on virus spread, not only on whitefly counts. Third, a formal systematic review of field evidence once enough well-reported trials exist to support one.

5.5 Practical Reading for Advisers and Growers

For an adviser, the sensible position is neither to dismiss neem nor to promise results. A grower who wishes to use it can run a small, recorded comparison on the farm: treated and untreated strips of similar crop and age, with the same spray equipment, counts taken from the same leaf positions on the same days, and the product and its source written down. Notes on rain, spray dates and neighbouring crops are as valuable as the

counts themselves [17, 37].

Such a comparison is not a trial and should not be reported as one. It can still show whether the product fits the farm, whether coverage of leaf undersides is achievable with the available sprayer, and whether the effect is large enough to notice against the ordinary patchiness of whitefly. The wider question of how large and how reliable the effect is will be answered by designed field work and by later synthesis of its results.

6. Conclusion

Neem-based products can suppress whitefly in cotton, and the way they do so is well understood. What is much less certain is how reliably they do it in a working field. Active content that varies between batches, rapid degradation, coverage of leaf undersides, immigration of adults and the spray history of the crop all push field results away from what bioassays suggest, and some non-target effects are likely. We think the fair reading is that neem belongs in integrated management as one component, applied with realistic expectations and tested properly, and that claims of reliable field control should wait for better-designed and better-reported trials.

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9. Conflict of Interest

The authors declare no conflict of interest.

10. Author Contributions

E.N. conceived the review and wrote the sections on whitefly biology and cotton protection. L.B. wrote the sections on neem chemistry and non-target effects. L.v.d.H. wrote the sections on trial design and field variability. All authors revised the manuscript and approved the final version.

11. Ethics Statement

This is a review of published literature. No animals were used 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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