

Bioefficacy of Entomopathogenic Fungi Against Pod Borer in Chickpea

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ABSTRACT

Entomopathogenic fungi, chiefly *Beauveria bassiana* and *Metarhizium anisopliae*, are often proposed as biological alternatives for managing the pod borer *Helicoverpa armigera* in chickpea, and laboratory bioassays regularly report high mortality of larvae. This narrative review asks how far those results carry into the crop. It draws on published work on the biology of the pest and the fungi, on formulation, persistence and strain variation, and on compatibility with other pest management practices, and it reports no new data. The central difficulty is a gap between the petri dish and the canopy: conidia applied to chickpea foliage face sunlight, heat, dry spells and an unfriendly leaf surface, while larvae spend part of their life inside pods, out of reach of a spray. Isolates differ widely in their tolerance of heat and ultraviolet radiation, so a strain that excels in the laboratory may perform poorly outdoors, and fungicides and some insecticides can reduce the viability of conidia. The review concludes that these fungi are credible components of integrated management, most promising against exposed young larvae and soil-dwelling stages, but that their field efficacy on chickpea is not established by the evidence available, and it sets out the trial design and reporting that would settle the question.

Keywords: Entomopathogenic fungi; *Beauveria bassiana*; *Metarhizium anisopliae*; *Helicoverpa armigera*; Chickpea; Biological control; Narrative review

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1. Introduction

Chickpea is a staple pulse for many farming households and a significant traded crop, valued for its protein and its place in rotations [1, 2]. Its genome has been sequenced, and breeders now have better tools than they once did [3], yet the crop in the field still loses a good deal of yield to insects. The most notorious of these is the pod borer, *Helicoverpa armigera*, a caterpillar that feeds on leaves and flowers early on and then bores into developing pods to eat the seeds.

The pest is hard to manage for reasons that have little to do with chickpea itself. It feeds on a very wide range of plants, its moths move readily between fields and crops, and it breeds through several generations in a season [4, 5, 6]. It has also spread; its arrival in South America and the modelling of its potential range in North America have turned a regional problem into a global one [7, 8]. Growers have leaned heavily on synthetic insecticides, and resistance to several chemical groups has been documented in the Indian subcontinent, most thoroughly in cotton [9, 10]. The search for alternatives is therefore a practical

necessity and not only a matter of fashion.

Entomopathogenic fungi are among the most frequently proposed alternatives. *Beauveria bassiana* and *Metarhizium anisopliae* infect insects directly through the cuticle, so a larva does not have to eat anything for infection to start [11, 12]. Products based on these fungi have been developed in many countries [13, 14], and papers reporting high mortality of *H. armigera* larvae in the laboratory are easy to find. What is less easy to find is a clear account of how that mortality translates into protected pods.

This review is about that translation. A laboratory bioassay is performed under conditions chosen to let the fungus succeed: a known dose, a susceptible larval stage, a steady temperature and high humidity, and no sunlight. A chickpea canopy offers none of this. We set out what is known about the pest, the fungi and the ways in which formulation, strain and the rest of the pest management programme shape the outcome, and we ask how much confidence the existing evidence supports. The article is a narrative review and reports no new data. The aim is a fair account of what has been shown and what has merely been repeated.

2. Literature Review

2.1 The Pest and Its Exposure to a Fungal Spray

To judge any control measure one has to know when and where the pest is exposed to it. In *H. armigera*, eggs are laid on foliage, buds and flowers, and the newly hatched larvae feed at first on the plant surface before moving to flowers and pods [4, 5]. Older larvae spend much of their feeding time with the front of the body inside a pod, and pupation takes place in the soil. There are, in other words, three quite different targets: exposed young larvae on leaves, older larvae partly shielded in pods, and pupae in the soil.

A contact pathogen can in principle reach the first and third of these. The second is the difficult one, because a spray deposited on the outside of a pod does not necessarily reach a larva that is feeding within, although larvae moving between pods and leaves cross treated surfaces. This is why the timing of an application relative to the pest's life cycle matters so much more for a fungus than the label of the product might suggest. A larva that has already bitten into a pod has, for practical purposes, left the reach of the spray.

The pest's host range complicates matters further. Work on heliothine pests argues that a host plant

should be defined by whether larvae can complete development on it and not merely by whether eggs are found there, and that the pattern of plant use shapes where populations build up [6]. A chickpea crop is thus one node in a landscape of hosts, and a control programme confined to the crop treats only part of the population.

Seasonality adds a further wrinkle. Moths arrive over an extended period and eggs hatch over several days, so at any moment a field holds a mixture of eggs, small larvae, older larvae and pupae in proportions that shift from week to week. A single application therefore meets different stages in different proportions depending on its date, and two trials that sprayed at different points in the pest's cycle may be testing quite different things even when the product is the same [4, 6].

2.2 The Case for Alternatives to Synthetic Insecticides

Resistance in *H. armigera* to major insecticide groups was documented in surveys of the Indian subcontinent decades ago [10], and later work on the main pests of cotton showed that the problem had persisted [9]. An important qualification is that much of this evidence comes from cotton, a crop sprayed far more intensively than chickpea, so it cannot be read as a measure of resistance in chickpea fields. It does show, however, that populations moving between crops carry their resistance with them.

Biological agents offer a different mode of action, and a pathogen that kills by growing through the cuticle is not affected by the detoxification mechanisms that protect insects against many chemicals. Reviews of insect pathogens as control agents emphasise this promise, and they emphasise equally that adoption has been uneven and that efficacy under field conditions has often fallen short of expectation [14, 15]. That tension is the subject of the rest of this article.

2.3 The Fungi: Identity and Ecology

The two genera most often tested against the pod borer are often spoken of as though each were a single, uniform organism. They are not. Molecular work has shown that *Beauveria* contains several species that look alike [16], and that *Metarhizium* is a complex of lineages with different habitats and host associations [17, 18]. Table 1 sets out how the two compare on points relevant to a chickpea crop. Where the table says that isolates vary, it means it: the spread within a species is wide enough that the species name alone is a weak guide to behaviour in the field.

Table 1. The two fungi most often tested against the pod borer, compared qualitatively.

Attribute	<i>Beauveria bassiana</i>	<i>Metarhizium anisopliae</i>
Taxonomy	Cryptic diversity recognised [16]	Species complex, several lineages [17]
Usual habitat	Soil, plant surfaces and insects [19]	Mostly soil-associated, often near roots [18, 20]
Temperature response	Differs by isolate and origin [24]	Differs by isolate and origin [25]
Sunlight tolerance	Varies among isolates [39]	Reduced by solar radiation [29]
Products	Widely formulated [13, 27]	Widely formulated [13, 26]
Safety reviews	Reviewed in detail [32]	Reviewed in detail [33]

Note: Qualitative summary of the cited literature. Isolate-to-isolate differences within each species are often larger than differences between the species.

In nature, *Beauveria* is found in soil, on plant surfaces and in insects, while *Metarhizium* is more tied to soil and the root zone [19, 20]. These habits matter. A soil-dwelling fungus is adapted to a stable, dark and humid environment and may be poorly equipped for a sunlit leaf, whereas the soil is exactly where a moth pupates. A fungus applied to the foliage, by contrast, is being asked to do something that its ecology may not have prepared it for.

2.4 How Infection Works and What It Needs

Infection begins when a conidium lands on the cuticle, adheres, germinates and penetrates, using a combination of mechanical pressure and cuticle-degrading enzymes [11, 21]. The cuticle is not a passive barrier: its chemistry affects whether a spore attaches and germinates, and the fungus responds with a battery of enzymes and surface proteins [22]. Once inside, the fungus grows through the haemocoel, and when the insect dies it may emerge and sporulate on the cadaver if conditions allow [12].

Each stage has environmental requirements. Germination needs moisture at the cuticle surface, growth needs a tolerable temperature, and sporulation on a cadaver is favoured by humid conditions. Temperature does more than permit or prevent growth: because both host and pathogen respond to it, the outcome of an infection can be shifted by the thermal environment in ways that a constant-temperature bioassay cannot reveal [23]. Work on isolates from different origins shows that their growth responses to temperature are far from identical [24, 25]. A result obtained at a constant, favourable temperature says little about a canopy that swings between cool nights and hot

afternoons.

2.5 Production, Formulation and Persistence

A fungus has to be grown, dried or suspended, stored and delivered, and each step can change its performance. The ecological considerations behind production and formulation are reviewed in some detail [26], and the production of *B. bassiana* as a microbial insecticide has been described from the fermentation stage through to field use [27]. The catalogue of commercial mycoinsecticides worldwide shows how varied the formulation types are [13].

Formulation is also the main way of shielding conidia from the field. Work on a related *Metarhizium* against locusts showed that oil-based formulations can improve infection at low humidity [28], and that oils and sunscreen compounds can protect conidia from damaging ultraviolet radiation [29]. In *B. bassiana*, ultraviolet protectants have been tested for their effect on persistence [30]. These are not studies on pod borer or chickpea, and we cite them for the principle they establish rather than for any effect size; whether such protection pays off on a chickpea leaf is a separate question that has to be tested.

Persistence in general is governed by a familiar set of factors: sunlight, temperature, moisture, the plant surface and the activity of other microbes [15, 31]. A product that must be re-applied every few days to keep a population of viable conidia on the foliage is a different proposition, economically and logistically, from one that persists for weeks.

2.6 Safety, Non-Target Organisms and Endophytic Use

The safety record of these fungi has been reviewed in detail for both genera [32, 33], and the question of toxic fungal metabolites has been examined separately [34]. In general, the conclusion of these reviews is that the risks to humans and vertebrates are low for registered strains, though they stress that each isolate should be assessed. Non-target insects, including natural enemies of the pest, are a different matter, since a broad-spectrum pathogen can infect beneficial insects too [35].

There is also an emerging line of work in which the fungus is not sprayed on the surface but established inside the plant as an endophyte, which could in principle protect it from sunlight and drying [36, 37]. Reviews of the endophytic habit describe a range of effects on pests and pathogens and a range of ways to introduce the fungus [38]. We could not identify evidence that

this approach has been shown to protect chickpea from the pod borer, and it is best regarded as a hypothesis for now.

3. Materials and Methods

3.1 Scope and Question

The review asks one question in two parts: do entomopathogenic fungi, applied to chickpea, plausibly give useful control of the pod borer, and what accounts for the gap between laboratory and field results? The question was split into the matters that a convincing efficacy study would have to address: the identity of the isolate, the way it was produced and formulated, the life stage of the pest that was exposed, the environment in which the fungus had to work, and the other inputs applied to the crop. None of these steps is hard, but each is easy to skip when a result looks good.

3.2 Literature Assembly

The review draws on peer-reviewed work in four areas: the biology and management of *Helicoverpa* species; the taxonomy, ecology and infection biology of *Beauveria* and *Metarhizium*; formulation, persistence and environmental stress; and compatibility with other pest management practices. Sources were chosen for relevance, standing in the field and clarity of method. Work on other insects and other crops is used for what it teaches about the fungi and their limits, not as evidence of effects on the pod borer in chickpea.

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. A consequence is that the article is a better guide to what a sound efficacy study should contain than to the exact size of any reported effect, and it avoids quoting figures from individual efficacy trials that could not be checked against the primary papers for this article.

3.3 Appraisal Framework

To judge how far a report of field efficacy can be trusted, we used a short set of questions, listed in Table 2. They are not a scoring system. Each question asks whether the information needed to interpret a result is present, since an efficacy figure without that information cannot be transferred to another field. Several of the questions overlap, and a report may answer one by accident while leaving its neighbour untouched, which is why we ask them separately.

Table 2. Questions to ask of any report of field efficacy against the pod borer.

Question	Why it matters	Often missing?
Which isolate, and from where?	Strains differ in heat and light tolerance [25, 39]	Often
What was applied?	Formulation changes survival [26, 28]	Sometimes
When in the day and season?	Sunlight and weather govern persistence [15, 31]	Often
Which larval stage was present?	Pods shelter older larvae [4, 5]	Very often
What else was sprayed?	Fungicides can harm conidia [41, 42]	Often
How was spore viability checked?	Dose reaching the plant is unknown otherwise	Rarely stated

Note: The last column gives the authors' reading of what is commonly missing from reports; it is a judgement from the cited literature, not a count.

4. Results

4.1 What Laboratory Bioassays Show

Laboratory bioassays against lepidopteran larvae are, in general, designed to give the fungus its best chance. Larvae are exposed to a measured dose by dipping, spraying or feeding on treated material, kept at a temperature and humidity favourable to infection, and shielded from light [12, 15]. Under such conditions many isolates of *B. bassiana* and *M. anisopliae* cause substantial mortality, and this is the source of the optimism in the literature. Such experiments are valuable for screening because they separate the fungus's intrinsic capacity from the confounding effects of the environment.

They are less informative about the field for the same reason. The result depends on the isolate, the dose, the stage of larva and the method of exposure, so figures from different laboratories are not directly comparable, and a mortality figure from a dipped larva says nothing about whether a sprayed larva on a pod receives a comparable dose. Figure 1 sketches the factors that lie between a laboratory result and control in the crop. This is why the same fungus can look excellent in one report and unremarkable in the next.

Speed of kill is another feature that bioassays tend to flatter. Infection takes time, and a larva that has been infected but is not yet dead can go on feeding for a while. In a crop that delay is counted in damaged pods, so survival-time measures from the laboratory need to be read alongside measures of feeding and damage, not instead of them [11, 12].

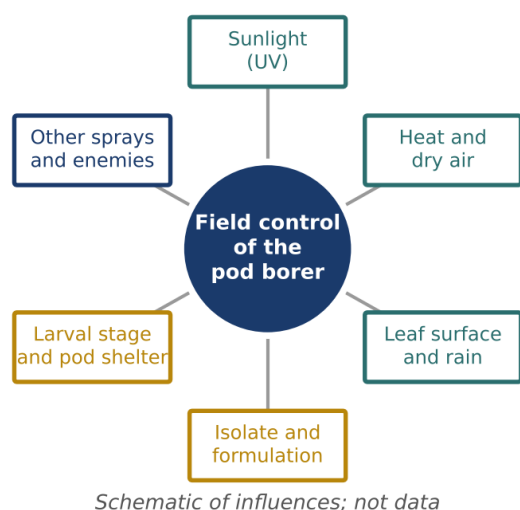


Figure 1. Factors that stand between a laboratory result and field control of the pod borer (schematic, not data).

4.2 Why Field Performance Often Falls Short

The first and most widely discussed stress is solar radiation. Ultraviolet light damages conidia, delays germination and reduces culturability, and tolerance differs markedly among isolates [29, 39]. Protective formulations can reduce the damage [29, 30], but they add cost and complexity. For a fungus applied to chickpea foliage in a sunny climate, exposure in the first hours after spraying is likely to be decisive.

Temperature is the second. Isolates differ in the range of temperatures at which they grow and in how well their conidia survive heat [24, 25], and the thermal biology of the host adds a further layer [23]. Humidity is the third: germination and sporulation depend on moisture near the cuticle, and a canopy that dries quickly after dawn gives the fungus a short window. Oil formulations are one response to this problem, at least in the locust work cited earlier [28]. Rain can wash conidia off the leaf, though how much remains is a question for each formulation and crop.

The plant surface may be a fourth stress. Chickpea foliage carries glandular hairs that secrete an acidic exudate, and it is often suggested that this makes the leaf a harsh surface for conidia; we found no study that measured conidial survival on chickpea leaves directly, so the suggestion should be treated as a hypothesis worth testing. Finally, the target itself moves: the larva that was exposed on a leaf at the time of spraying may be inside a pod a few days later. Figure 2 summarises our reading of how these stresses bear on the stages of fungal action.

	Persist on leaf	Germinate	Reach larva	Sporulate
Sunlight (UV)	likely	possible	minor	minor
Heat	possible	likely	possible	possible
Dry air	possible	likely	possible	likely
Rain	likely	minor	minor	possible
Leaf surface	possible	likely	possible	minor
Pod shelter	minor	minor	likely	minor

Authors' qualitative judgement of the cited literature; not measured data

Cell text: how much the stress is likely to matter at that stage

Figure 2. Qualitative reading of how field stresses bear on stages of fungal action (authors' judgement, not data).

None of this means that field control is unattainable. It means that the field effect is a product of many conditions, and that the conditions in a laboratory are unusually favourable. A fungus that reduces pest numbers on a cloudy, humid week may do little in a dry, bright one. Reviews of the ecology of inundative use make precisely this point, and they argue that the environment needs to be part of the design of a programme and not an afterthought [15, 31]. Small differences in weather add up over the days a spray has to work.

4.3 Strain Variability

The choice of isolate is the factor over which the grower and researcher have most control, and the literature leaves no doubt that it matters. Isolates of *B. bassiana* from different origins differ in the temperatures at which they grow [24], isolates of *Beauveria* differ in their tolerance of ultraviolet-B [39], and isolates of *M. anisopliae* differ in conidial thermotolerance [25]. Selection studies in other pests have shown that virulence, thermal requirements and other traits can be combined to pick candidates [40].

Two cautions follow. First, the best isolate in a laboratory screen is not necessarily the best in the field, because the traits that win a screen (speed of kill at a favourable temperature) differ from those needed outdoors (tolerance of light and heat). A screen run at a single constant temperature will tend to pick the same isolates every time. Second, because the species are complexes with cryptic lineages [16, 17, 18], an isolate identified only at species level may be poorly characterised, and two isolates under the same name can behave quite differently. Reports should state the isolate, its origin and how it was maintained. The point is not that a trial is poor, only that its result travels less

far than its abstract suggests.

4.4 Compatibility with Other Pest Management Practices

A chickpea crop is rarely managed with a single input. Fungicides are applied against foliar diseases, insecticides against the pod borer itself, and these can affect a living fungal agent directly. An early study showed that fungicides influence the survival of *B. bassiana* inoculum [41], and work on neonicotinoid insecticides found that their compatibility with entomopathogenic fungi depended on the product and the fungus [42]. Table 3 collects the main compatibility questions.

Sequence and spacing are the practical tools for managing such conflicts. A commonly suggested precaution is to keep a fungal application apart in time from fungicide sprays and to check product labels and published compatibility tests before tank-mixing anything with living conidia [26, 41]. The suggestion is sensible, but it rests largely on laboratory compatibility studies, and the field consequences of a short interval between sprays have rarely been measured.

Table 3. Compatibility of fungal products with other components of pest management in chickpea.

Component	Main concern	Practical step
Chemical fungicides	Can reduce survival of conidia [41]	Test the pair; separate the sprays
Synthetic insecticides	Some inhibit growth of the fungus [42]	Check the product before mixing
<i>Bacillus thuringiensis</i>	Interaction can be favourable [43]	Test the combination on larvae
Natural enemies	Fungus may also affect them [35, 44]	Time sprays; monitor beneficials
Host plant resistance	Plant traits affect larval exposure [6]	Match fungus to the cultivar
Resistance management	Different mode of action [14]	Rotate with other chemistries

Note: Evidence comes from the cited studies on other crops and pests; direct tests in chickpea are few. Entries are cautions, not rules.

Not every interaction is a problem. In Colorado potato beetle, combinations of *B. bassiana* and a *Bacillus thuringiensis* product gave a synergistic effect in the field [43], which suggests that a fungus can be a partner to other biological products. Whether the same is true for the pod borer in chickpea needs testing, and one cannot simply assume it.

Natural enemies deserve attention. Interactions between entomopathogenic fungi and predators or parasitoids can be neutral, harmful or even beneficial depending on the species and the timing

[35], and practices that conserve fungi in the agroecosystem may bring benefits beyond a single spray [19, 44]. The compatibility of a fungal product with a given crop cultivar is also worth considering, since plant traits influence how long larvae remain exposed on the surface [6].

4.5 Reading a Claim of Field Efficacy

A reader meeting a claim that a fungal product controlled the pod borer in chickpea can ask a short sequence of questions (Table 2 and Figure 3). Which isolate was used and how was it produced? What was the formulation, and was the viability of the spores checked before and after application? Which life stage was present when the spray went on? What else was applied to the crop in the same period? A report that answers all of these is rare, and one that answers none should be read as an observation and not as evidence that the product works.

Pod damage and larval counts are not the same thing. A product that reduces the number of small larvae on the foliage but leaves older larvae untouched may change damage less than the larval count suggests, and a result expressed only as mortality of larvae collected after treatment cannot show how many pods were saved. Where a report gives only one of these measures, the reader should be cautious about extending it to the other.

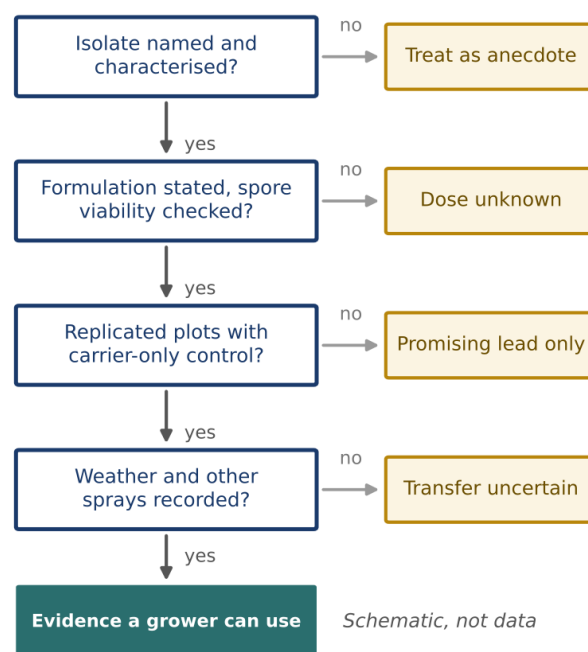


Figure 3. Decision path for judging a fungal product against the pod borer (schematic, not data).

Replication and design matter here as they do everywhere. Field plots that are small and close

together can interact, since moths and larvae move between them and a fungus applied in one plot may drift into another. A control plot sprayed with a carrier alone is needed to separate the effect of the fungus from the effect of the oil or surfactant. Without such controls a reported benefit cannot be attributed to the fungus.

5. Discussion

5.1 Interpretation and Practical Reading

The main finding of this review is conditional. Entomopathogenic fungi are credible components of an integrated programme against the pod borer, and the best-supported places for them are the exposed young larvae on the foliage and the soil-dwelling stages, where the fungus meets the pest in an environment that suits it or at a time when it is accessible [19, 44]. They are less well suited to protecting pods from older larvae that are partly inside the pod. Nothing in this reading argues against using these fungi; it argues for measuring what happens when they are used.

The second conditional concerns strain and formulation. A well-chosen isolate in a protective formulation is likely to behave differently from an unselected isolate in water. This implies that a claim about a fungus has to be read as a claim about a particular isolate in a particular product used under particular conditions, and it is the reason why we have stressed reporting throughout [26, 27].

A third point concerns the rest of the programme. A fungus that is compatible with the other inputs used on the crop can be integrated, and one that is not will need to be separated from them in time or replaced. These are manageable constraints, and they argue for care in planning and not for abandoning the approach [14, 43]. These points apply with equal force to any living biocontrol agent, not only to fungi.

Three findings would change this reading. A well-replicated field trial on chickpea showing sustained reduction of pod damage with a defined isolate and formulation would raise confidence considerably. Direct measurement of conidial survival on chickpea foliage would settle the question of the leaf surface. And evidence that endophytic establishment protects chickpea from the pod borer would open a route that avoids sunlight altogether [36, 38].

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 efficacy trials against the pod borer, because they could not be checked against the primary reports for this article. A reader who needs an effect size should consult the original studies directly and apply the questions in Table 2, or wait for a formal systematic review.

The review also relies on evidence from other insects, other crops and other fungal species, which are imperfect proxies for the pod borer in chickpea. The work on locusts, whiteflies and the Colorado potato beetle was done with different hosts, different environments and different questions. We have used it to frame hypotheses, and the conclusions 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 question would use a named, deposited isolate, state how it was produced and formulated, and verify the viability of the conidia before application. It would apply the product at a defined time of day and stage of crop and pest, and record temperature, humidity, sunlight and rain across the period of the trial. Replicated plots with adequate separation and a carrier-only control would be required, and damage to pods and the number of larvae of each stage would both be reported [15].

Trials should also record the other inputs applied, so that interactions can be assessed. They should include more than one dose or application schedule, so that the shape of the response can be seen, and they should follow the crop long enough to show whether the effect lasts. These requirements are demanding, but they are the ones that distinguish a result a grower can use from one that only supports a hunch.

Reporting deserves a sentence of its own. Many of the gaps catalogued in Table 2 could be closed at almost no cost, since the isolate, the formulation and the weather during the trial are known to the authors at the time of writing. A short structured statement of these items, placed in the methods of every efficacy report, would make later comparison and synthesis far easier than it is today, and it would let growers and advisers judge for themselves how closely a trial resembles their own conditions [13, 15].

5.4 Directions for Future Work

Three needs stand out. First, a formal systematic review with a transparent search and quality

appraisal of field trials against *H. armigera*, extending beyond chickpea. Second, well-designed field trials in chickpea with the features above, ideally testing isolates selected for heat and light tolerance rather than for speed of kill alone [39, 40]. Third, work on the compatibility of fungal products with the fungicides and insecticides in common use on chickpea, and on the possibility of endophytic establishment [36, 37].

5.5 Practical Reading for Advisers and Growers

For an adviser, the sensible position is neither to dismiss these fungi nor to promise results. A grower who wishes to try a product can do so as a small, recorded comparison: treated and untreated strips in the same field, sprayed late in the day when practical, with larval counts and pod damage recorded in the same way for both. Notes on the weather and on anything else sprayed are as valuable as the counts, because they allow the result to be interpreted.

Such a comparison is not a substitute for a trial and should not be reported as one. It can nonetheless tell a grower whether the practice is workable on his or her own farm, and whether any difference is large enough to see against the ordinary variation between fields and seasons. The broader question of effect size will be settled by designed trials and by systematic synthesis of their results [14, 34].

6. Conclusion

Entomopathogenic fungi are a plausible and attractive component of pod borer management in chickpea. The evidence, as we can responsibly summarise it, does not yet establish how much control they give in the field. What the literature does show is why laboratory results overstate field performance, which stresses matter most, how strain and formulation can narrow the gap, and what a fair trial and a fair report would contain. Readers should treat claims of large field gains with caution until they meet those standards.

For the practitioner the message is practical rather than discouraging. These fungi can be tried, provided the isolate is known, the product is fresh, the timing suits the pest and the other sprays are compatible. For the researcher, the opportunity is a set of well-designed field trials that turn a promising laboratory result into a measured one that growers can rely on.

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9. Conflict of Interest

The authors declare no conflict of interest.

10. Author Contributions

S.C. conceived the review and wrote the sections on pest biology and field persistence. G.V. wrote the sections on formulation, strain variation and compatibility. G.P. wrote the sections on the infection biology of the fungi and on trial design. 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.

13. References

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