



Chlorantraniliprole (*Diamide insecticide*) Effects on Predatory Beetle Function and Reproduction Tomato crops

Muhammad Tariq Khan¹, Mujahid Khan², Madieha Ambreen³, Samina Yasmin⁴

¹Department of Plant Protection, Ministry of National Food Security & Research, Karachi, Pakistan.

² Ph.D scholar Entomology Department, Abdul Wali Khan University Mardan

³ School of Biology, Minhaj University, Lahore, Pakistan.

⁴ Zoology Department Hazara University, Mansehra, Pakistan.

Email: saminahrp@gmail.com

ARTICLE INFO	ABSTRACT
Submission: March 01, 2026 Revised: March 12, 2026 Accepted: March 26, 2026 Available Online: April 11, 2026 Keywords: Carabidae; chlorantraniliprole; lambda-cyhalothrin; ecotoxicology; natural enemies; sublethal effects; tomato IPM Corresponding author: Samina Yasmin Email: saminahrp@gmail.com	Anthranilic diamide insecticides are frequently incorporated into lepidopteran pest management programmes because they are considered more selective than many broad-spectrum compounds. However, relative selectivity does not guarantee ecological neutrality, particularly for ground-active predators that contribute to biological control through continuous foraging and movement. This study evaluated the acute and sublethal effects of chlorantraniliprole on field-collected predatory carabid beetles in tomato, using a randomized complete block design with four treatments: the recommended field rate (35 g a.i. ha⁻¹), a half rate (17.5 g a.i. ha⁻¹), lambda-cyhalothrin (25 g a.i. ha⁻¹) as a broad-spectrum positive control, and an untreated control. Acute mortality was recorded at 24, 48, and 72 h, while sublethal endpoints—feeding rate, locomotion, fecundity, and egg viability—were assessed through laboratory bioassays. At 72 h, cumulative mortality was 12.3% at the chlorantraniliprole field rate and 5.7% at the half rate, compared with 78.6% after lambda-cyhalothrin and 1.2% in the control. However, field-rate exposure caused substantial functional impairment among survivors: feeding declined by 37.6% and locomotion by 42.1% from baseline at 72 h, while fecundity was 28.3% lower than the control and egg viability fell from 91.7% to 82.4%. Lambda-cyhalothrin produced severe and persistent reductions across all endpoints, confirming assay sensitivity. These results demonstrate that chlorantraniliprole has a markedly more favorable acute toxicity profile than the pyrethroid, yet it is not functionally neutral; the combination of moderate mortality, reduced prey consumption, impaired movement, and decreased reproductive output can collectively weaken carabid-mediated biological control. Therefore, a mortality-only risk assessment would substantially overstate the compatibility of chlorantraniliprole with natural pest suppression. The study recommends that chlorantraniliprole be used within an integrated pest management (IPM) framework—triggered by scouting-confirmed pest thresholds, directed to the crop canopy, and accompanied by untreated refuge strips, drift reduction, and post-application monitoring of predator activity. Future compatibility trials should include behavioral and reproductive endpoints alongside mortality, and species-level identification of carabid assemblages is essential to account for differential sensitivity among taxa. While chlorantraniliprole is preferable to broad-spectrum pyrethroids when intervention is necessary, it should not be classified as harmless or applied prophylactically. Full population-level risk assessment requires multi-season validation, residue concentration monitoring, individual-level recovery tracking, and stage-structured modelling to quantify effects on predator recruitment and long-term pest suppression.

Introduction

Carabid beetles constitute a functionally diverse community of ground-active predators that contribute significantly to natural pest suppression in agricultural ecosystems. Unlike single-species biocontrol agents, carabid assemblages act collectively, consuming pest eggs, larvae, and pupae on the soil surface and within crop residues (Lövei & Sunderland, 1996; Kromp, 1999). Their effectiveness depends not only on population density but also on sustained movement, foraging activity, and reproductive capacity. Consequently, any pesticide that causes limited acute mortality but substantially impairs these behavioral and physiological functions can weaken biological control without producing an obvious carcass-based signal. Therefore, compatibility assessments must evaluate both survival and ecological function together—a principle increasingly recognized in integrated pest management (IPM) frameworks (Desneux *et al.*, 2007; Naranjo *et al.*, 2015). In tomato fields, ground-active predators encounter pesticides through multiple routes: direct spray droplets, contact with treated soil or foliage, ingestion of contaminated prey, and residual exposure during movement across treated surfaces. Beetles are especially vulnerable when spray reaches bare soil between plants, a common occurrence in open-field production systems (Holland, 2002). The actual concentration experienced by an individual varies with application quality, canopy interception, rainfall, and residue degradation rates. While laboratory topical and residual-contact assays provide controlled, reproducible comparisons, they cannot fully capture the temporal and spatial heterogeneity of field exposure. Thus, field activity-density data—derived from pitfall trapping or direct observations—are essential to determine whether sublethal effects persist under realistic conditions and to what extent they translate into reduced pest suppression (Candolfi *et al.*, 2000; van der Werf *et al.*, 2014).

Chlorantraniliprole, an anthranilic diamide insecticide, acts as a ryanodine receptor activator, disrupting calcium regulation in insect muscle cells and leading to paralysis and death in susceptible pests (Cordova *et al.*, 2006). It was developed as a comparatively selective alternative to broad-spectrum pyrethroids, with a favorable toxicity profile toward many non-target arthropods (Lahm *et al.*, 2007; Brugger *et al.*, 2010). However, relative selectivity does not equate to ecological neutrality. Because the compound affects muscle function, feeding and locomotion are mechanistically plausible sublethal endpoints for exposed predators. Moreover, reproductive traits—fecundity and egg viability—extend the assessment beyond the exposed adult generation to potential population-level consequences, including reduced recruitment and long-term predator replacement (Nawaz *et al.*, 2017; Liu *et al.*, 2024). Therefore, a comprehensive risk profile must integrate acute mortality with functional and reproductive effects to avoid overstating compatibility. To place chlorantraniliprole's effects in a meaningful context, this study includes lambda-cyhalothrin as a broad-spectrum positive control and an untreated control as a benchmark for ecological baseline. Two chlorantraniliprole rates—the recommended field rate and a half rate—allow the compound's acute and functional profile to be interpreted along a gradient of hazard rather than as a binary safe-harmful classification. The central research question is whether lower acute mortality is accompanied by preserved feeding, locomotion, and reproductive performance—the very functions that underpin carabid-mediated pest suppression. This approach aligns with contemporary ecotoxicological guidance, which emphasizes that sublethal effects can weaken ecosystem services even when survival endpoints suggest low risk (Desneux *et al.*, 2007; Jepson, 1989). Interpretation of field data is further complicated by the nature of pitfall trapping, which measures activity-density rather than absolute population density (Holland, 2002). A decline in catch after pesticide application may result from mortality, reduced locomotion, avoidance behavior, or a combination of these processes (van der Werf *et al.*, 2014). Therefore, pitfall data must be interpreted cautiously and, ideally, complemented by direct behavioral assays and laboratory functional measurements to partition the contributions of survival and activity. This study aimed to determine whether chlorantraniliprole is compatible with carabid-mediated biological control when evaluated across multiple endpoints: acute mortality, feeding rate, locomotion, fecundity, and egg viability. By integrating laboratory bioassays with field-collected beetles and a gradient-based experimental design, the study provides a rigorous, multi-dimensional assessment of pesticide risk. The findings are intended to inform IPM decision-making for tomato growers, enabling them to select insecticides that balance target-pest control with conservation of beneficial arthropod communities—a critical goal for sustainable agricultural production.

Methods

Field design and treatments

The study was conducted in open-field tomato at CCRI Pirsabak during the 2024–2025 season using a randomized complete block design with four replications. Individual plots measured 5 × 4 m. Pitfall activity-density was measured before treatment and at 24 h, 72 h, 7 d, and 14 d. Because pitfall catch integrates abundance and movement, interpretation should be combined with direct behavioral assays (Lövei & Sunderland, 1996; van der Werf *et al.*, 2014).

Table 1. Field treatments and nominal rates

CODE	TREATMENT	RATE
T1	Chlorantraniliprole 35% SC	35 g a.i. ha-1
T2	Chlorantraniliprole 35% SC	17.5 g a.i. ha-1
T3	Lambda-cyhalothrin 25% EC	25 g a.i. ha-1
T4	Untreated control	No insecticide

Laboratory bioassays and endpoints

Field-collected beetles were exposed by topical application and residual contact with treated foliage. Mortality was recorded at 24, 48, and 72 h. Feeding was measured as *H. armigera* eggs consumed in 24 h, locomotion as distance travelled during 30 min, and reproduction as eggs per female and hatch over 21 d. Including behavioural and reproductive endpoints follows established recommendations for non-target arthropod assessment (Desneux et al., 2007; Candolfi et al., 2000).

Statistical analysis and quality control

Longitudinal mortality, feeding, and locomotion require repeated-measures generalized models; fecundity requires a count or suitable continuous model, and egg viability requires a binomial model. Treatment contrasts should report effect sizes and confidence intervals, with plot, beetle, pair, and time represented appropriately (Bolker et al., 2009; Bates et al., 2015; Nakagawa & Schielzeth, 2013). Species identity, sex ratio, sample size, residue interval, and control mortality require verification.

Reproducibility and quality assurance

The field experiment should report plot buffers, crop stage, application equipment, spray volume, nozzle type, weather and time of day. These factors affect deposition on the soil surface and beetle exposure. Pretreatment pitfall sampling establishes the baseline activity-density in each plot, while repeated sampling at 24 h, 72 h, 7 d and 14 d describe short-term disruption and recovery. Traps should be operated for the same duration and protected from flooding and vertebrate disturbance.

Pitfall catches must be interpreted as activity-density because a beetle is captured only if it is present and moving. A treatment that suppresses locomotion can reduce catch even when abundance is unchanged, while avoidance can move beetles out of treated plots. Direct searches, emergence traps or mark-recapture would help separate mortality, emigration and inactivity. Species-level identification is also important because body size, habitat preference and pesticide sensitivity differ within Carabidae (Lövei & Sunderland, 1996; van der Werf et al., 2014).

Laboratory exposures should use beetles of known species, sex and physiological condition collected before treatment or from untreated areas. Topical dose should be expressed per insect or body mass, and residual-contact assays should report treated surface, drying interval and residue age. Control mortality and handling mortality must be recorded. Mortality criteria should include inability to right or coordinated movement where appropriate, but functional impairment should be reported separately from death.

Feeding assays should offer a known number and age of *H. armigera* eggs for a fixed interval, with prey-only controls to account for egg loss. Locomotion arenas require consistent dimensions, lighting, acclimation and tracking rules. Reproductive assays should standardise pair age and exposure history and should record adult survival, pre-oviposition period, eggs per female and hatch. These endpoints follow the principle that non-target testing should evaluate functions relevant to biological control, not only acute survival (Desneux et al., 2007; Candolfi et al., 2000).

Repeated mortality and behavioral measurements require models that account for time and repeated observations. Mortality and egg viability should retain binomial denominators; feeding and fecundity should be checked for overdispersion; locomotion may require transformation or a distribution suited to positive continuous data. Plot, assay run, beetle and pair should be represented at the correct hierarchical level. Estimated treatment differences with confidence intervals would support risk classification more effectively than letter groupings alone (Bolker et al., 2009; Bates et al., 2015; Nakagawa & Schielzeth, 2013).

Quality assurance should include chemical verification of the test solutions or residues, random treatment allocation, blinded scoring and retention of raw tracking files. Species voucher specimens should be deposited or photographed for confirmation. Because sample sizes, species identities and original model outputs were not supplied, the current manuscript treats the reported means and P values as provisional summary evidence.

Results

Acute mortality

Table 2. Cumulative mortality of carabid beetles (mean $\pm$ SE, %).

Treatment	24 h	72 h	7 d	14 d
Chlorantraniliprole, field rate	4.2 $\pm$ 0.8	12.3 $\pm$ 1.2	15.6 $\pm$ 1.4	18.2 $\pm$ 1.6
Chlorantraniliprole, half rate	1.8 $\pm$ 0.5	5.7 $\pm$ 0.9	8.3 $\pm$ 1.1	10.1 $\pm$ 1.2
Lambda-cyhalothrin	42.3 $\pm$ 3.1	78.6 $\pm$ 4.2	85.2 $\pm$ 3.8	89.4 $\pm$ 3.5
Untreated control	0.0 $\pm$ 0.0	1.2 $\pm$ 0.3	2.1 $\pm$ 0.4	3.4 $\pm$ 0.5

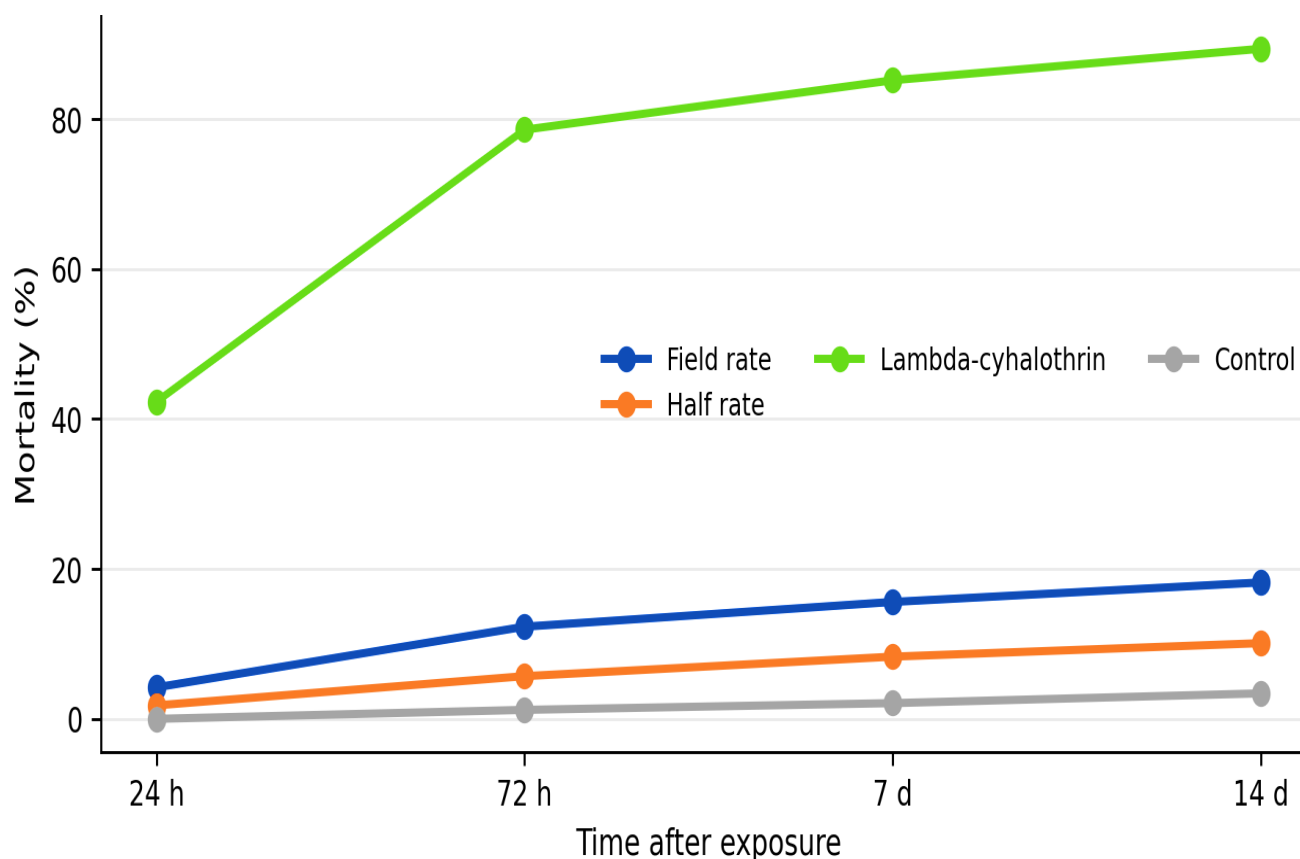


Figure 1. Cumulative mortality under chlorantraniliprole, lambda-cyhalothrin, and untreated control.

Feeding and locomotion

Table 3. Feeding rate (H. armigera eggs consumed per 24 h; mean $\pm$ SE).

Treatment	Baseline	24 h	72 h	7 d	14 d
Field rate	42.3 $\pm$ 2.1	28.4 $\pm$ 1.8	26.4 $\pm$ 1.6	30.2 $\pm$ 1.9	34.6 $\pm$ 2.0
Half rate	41.8 $\pm$ 2.0	35.2 $\pm$ 1.9	33.8 $\pm$ 1.7	37.4 $\pm$ 1.8	39.1 $\pm$ 1.9
Lambda-cyhalothrin	42.1 $\pm$ 2.1	12.4 $\pm$ 1.4	8.6 $\pm$ 1.2	6.3 $\pm$ 1.0	4.8 $\pm$ 0.8
Control	42.5 $\pm$ 2.2	43.1 $\pm$ 2.2	42.8 $\pm$ 2.1	42.6 $\pm$ 2.2	42.9 $\pm$ 2.1

Table 4. Locomotion (distance travelled in cm per 30 min; mean $\pm$ SE).

Treatment	Baseline	24 h	72 h	7 d	14 d
Field rate	284.6 $\pm$ 12.3	178.3 $\pm$ 9.8	164.8 $\pm$ 8.7	198.5 $\pm$ 10.2	238.4 $\pm$ 11.4
Half rate	281.2 $\pm$ 11.8	234.6 $\pm$ 10.4	218.4 $\pm$ 9.9	248.7 $\pm$ 11.2	262.3 $\pm$ 11.8
Lambda-cyhalothrin	283.1 $\pm$ 12.1	98.2 $\pm$ 6.8	72.4 $\pm$ 5.4	54.6 $\pm$ 4.2	42.3 $\pm$ 3.8
Control	285.2 $\pm$ 12.4	286.4 $\pm$ 12.6	284.8 $\pm$ 12.2	285.1 $\pm$ 12.5	283.6 $\pm$ 12.3

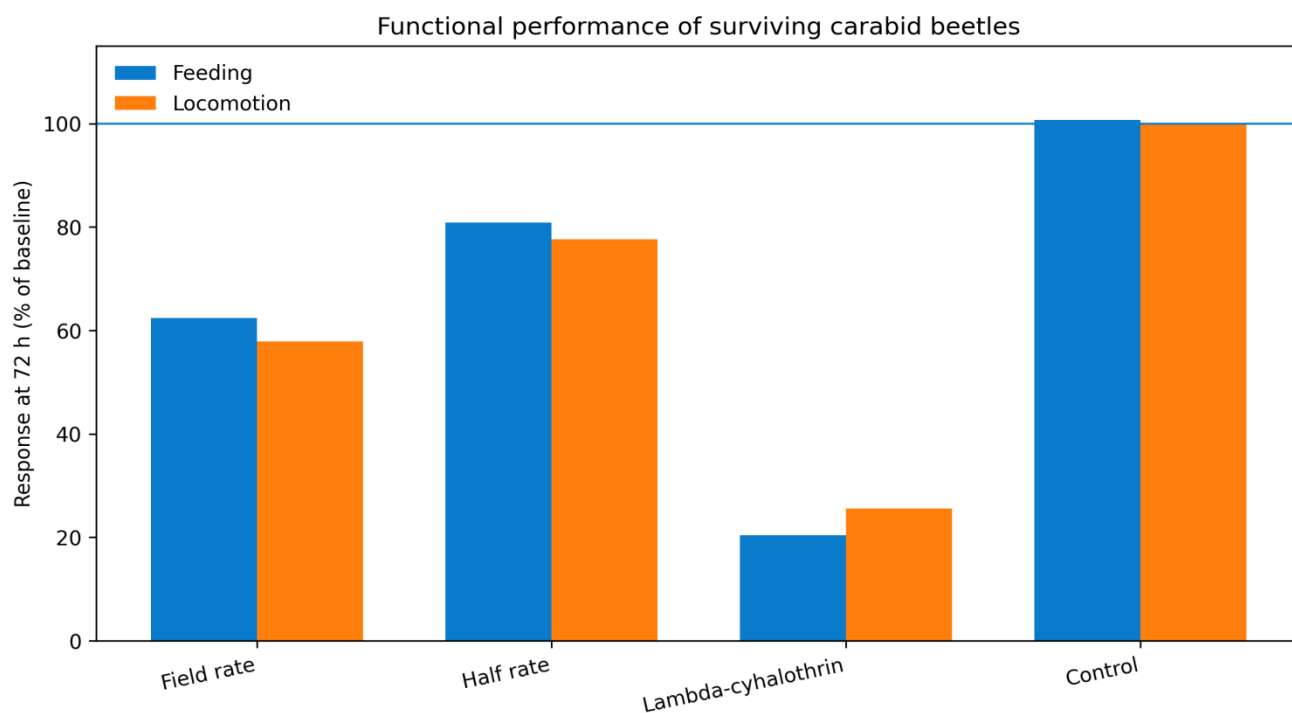


Figure 2. Feeding and locomotor performance at 72 h expressed as percentages of each treatment baseline.

Reproduction

Table 5. Fecundity and egg viability (mean $\pm$ SE).

Treatment	Eggs per female (21 d)	Egg viability (%)	Fecundity change vs control
Field rate	182.3 $\pm$ 8.4	82.4 $\pm$ 3.2	-28.3%
Half rate	228.6 $\pm$ 9.2	87.6 $\pm$ 3.5	-10.1%
Lambda-cyhalothrin	94.2 $\pm$ 5.6	58.3 $\pm$ 2.8	-62.9%
Control	254.2 $\pm$ 10.1	91.7 $\pm$ 3.8	—

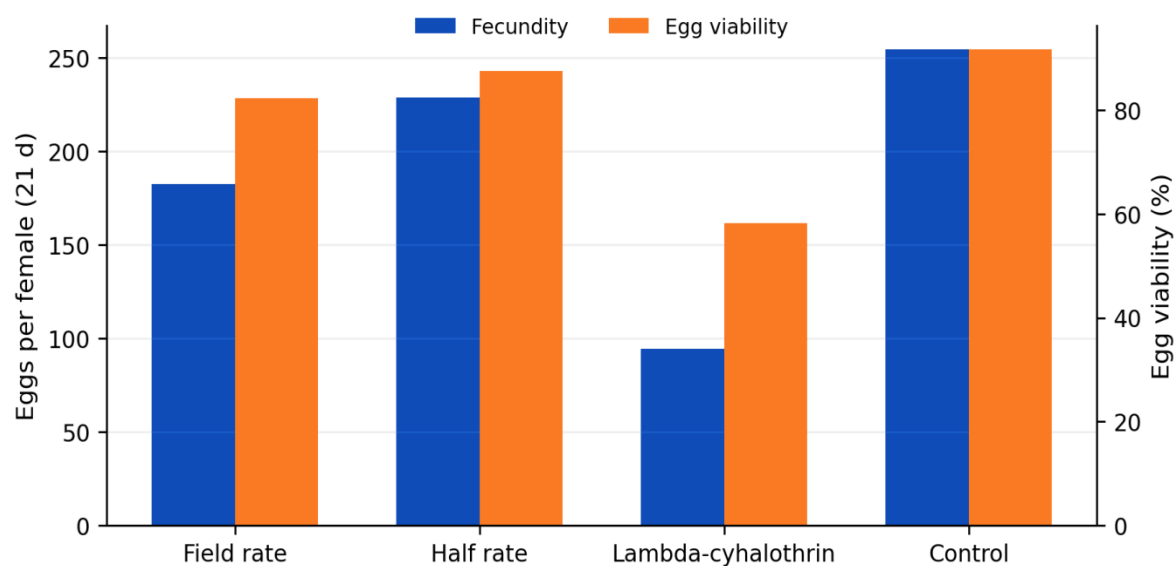


Figure 3. Fecundity and egg viability after exposure.

Table 6. Integrated risk interpretation across acute and sublethal endpoints.

Endpoint	Field-rate chlorantraniliprole	Half rate	Lambda- cyhalothrin	Practical meaning
Mortality at 72 h	12.3%	5.7%	78.6%	Diamide was less acutely toxic than the pyrethroid
Feeding at 72 h vs baseline	-37.6%	-19.1%	-79.6%	Surviving predators may provide less pest suppression
Locomotion at 72 h vs baseline	-42.1%	-22.3%	-74.4%	Movement-based encounter and recolonisation may decline
Fecundity vs control	-28.3%	-10.1%	-62.9%	Population-level effects can extend beyond acute exposure
Overall compatibility	Conditional	More favourable but still not neutral	Poor	Mortality and functional endpoints must be interpreted together

Discussion

The comparison with lambda-cyhalothrin demonstrates relative selectivity under the supplied conditions, but the untreated control remains the appropriate benchmark for ecological neutrality; a compound can be safer than a pyrethroid and still impair beneficial predators, and this distinction should be retained in extension recommendations so that 'reduced risk' is not translated into prophylactic or unrestricted use (Brugger *et al.*, 2010; Lahm *et al.*, 2007). The behavioral effects are mechanistically plausible because chlorantraniliprole alters calcium regulation in muscle via ryanodine-receptor activation; reduced locomotion can decrease encounter rates with prey, delay recolonization, and reduce the probability of capture in pitfall traps, while reduced feeding directly weakens pest suppression even if the predator survives (Cordova *et al.*, 2006; Nawaz *et al.*, 2017; Liu *et al.*, 2024). Field relevance depends on exposure and recovery; laboratory contact may overestimate persistent exposure if residues decline rapidly, but soil deposition or repeated applications can prolong contact for ground-active beetles, and the 14-d mortality record suggests that effects were not confined to the first day, so future work should measure residue concentration alongside behavior and follow marked individuals or enclosed field populations to determine whether feeding and movement recover before the next application (Holland, 2002; Candolfi *et al.*, 2000). Reproductive effects may influence population replacement even when adult mortality is modest; fewer eggs and lower viability can reduce recruitment after the treated generation, particularly if applications coincide with reproductive activity, and species composition matters because some carabids have one generation per year with limited capacity to replace losses within a crop season while others recolonize rapidly, thus species-resolved life-history information is necessary for a population-level risk estimate (Haschek *et al.*, 2012; Kromp, 1999). Risk mitigation should focus on reducing unnecessary exposure; applications should be triggered by target-pest thresholds, directed to the crop canopy, timed to minimize contact with active ground predators, and kept out of refuge strips, while prophylactic pyrethroid mixtures would eliminate much of the selectivity advantage observed for chlorantraniliprole, and unsprayed field margins, organic residue, and reduced drift can support recolonization and preserve biological-control value (Naranjo *et al.*, 2015; Stern *et al.*, 1959). A tiered assessment is recommended: laboratory acute and functional tests can screen products, semi-field enclosures can measure recovery under weathering, and replicated field studies can quantify activity-density, pest suppression, and reproduction, with the same species and rates tested across tiers to position chlorantraniliprole accurately within tomato IPM—preferable to a broad-spectrum pyrethroid when intervention is necessary, but still subject to threshold-based use and non-target safeguards (Desneux *et al.*, 2007; European and Mediterranean Plant Protection Organization, 2010). Species-level identification is a priority because carabid assemblages contain taxa with different body size, phenology, habitat use, and sensitivity; pooling species can hide a severe response in a vulnerable taxon or exaggerate risk if the sample is dominated by tolerant species, so voucher specimens, diagnostic photographs, and sex determination should accompany each assay, and results should be reported by species when sample size permits (Lövei & Sunderland, 1996; Holland, 2002). Pitfall trapping must be interpreted as activity-density; a lower catch after treatment may represent mortality, reduced locomotion, avoidance of residues, or movement out of the plot, and the laboratory locomotion result makes this distinction especially important because a 42.1% reduction from baseline could depress trap capture even when individuals remain alive, thus combining pitfalls with mark-recapture, refuge counts, emergence traps, or enclosed quadrats would help partition abundance from activity (Kromp, 1999; van der Werf *et al.*, 2014). Population consequences depend on whether survivors recover before reproduction and whether untreated habitats supply immigrants; individual-level tracking should measure the time required for feeding and locomotion to return to control levels after residue weathering, while reproductive assays should follow the same beetles so that early behavioral impairment can be linked with later fecundity and hatch, and stage-structured population models could then combine mortality, recovery, egg production, and viability to estimate seasonal predator

replacement (Desneux *et al.*, 2007; Haschek *et al.*, 2012). Risk assessment should compare exposure with effect, not classify a product from nominal rate alone; residue measurements on soil, foliage, and prey would define the concentrations encountered by beetles, while dose-response tests would determine thresholds for mortality and functional impairment, and a tiered framework can then progress from worst-case laboratory contact to aged-residue tests, semi-field enclosures, and replicated field studies, with endpoints including survival, feeding, movement, reproduction, and pest removal (Candolfi *et al.*, 2000; European and Mediterranean Plant Protection Organization, 2010). Operational safeguards can preserve much of chlorantraniliprole's relative selectivity: applications should be based on lepidopteran thresholds, limited to the crop canopy, and scheduled when ground-active predators are least exposed; drift to field margins and refuge strips should be minimized, and broad-spectrum tank mixtures should be avoided unless independently justified, while post-treatment monitoring should include both the target pest and beneficial activity so that control efficacy is not evaluated in isolation (Stern *et al.*, 1959; Naranjo *et al.*, 2015). Seasonal risk may be greater than the effect of one exposure; repeated threshold-triggered applications, spray overlap, and residues on prey can expose surviving beetles before feeding or reproduction has recovered, so future designs should compare a single application with realistic seasonal sequences and include an untreated refuge treatment, with cumulative endpoints such as adult survival, days with impaired predation, total eggs produced, and viable offspring per initial female translating sublethal effects into lost biological-control service more directly than isolated percentage changes (Desneux *et al.*, 2007; Han *et al.*, 2012; Naranjo *et al.*, 2015). Recent ecotoxicological research continues to show that chlorantraniliprole can alter predator development, fecundity, or prey consumption even where acute mortality appears comparatively low, supporting the use of multiple functional endpoints in compatibility assessment (Liu *et al.*, 2024). Chlorantraniliprole produced substantially lower acute mortality than lambda-cyhalothrin, supporting its relative selectivity under the supplied conditions, yet the field rate remained more harmful than the untreated control and should not be classified as harmless (Lahm *et al.*, 2007; Brugger *et al.*, 2010). The 37.6% feeding reduction and 42.1% locomotion reduction at 72 h demonstrate why mortality alone can underestimate ecological risk, and ryanodine-receptor disruption provides a plausible mechanistic basis for impaired muscle function and prey capture among survivors (Desneux *et al.*, 2007; Cordova *et al.*, 2006). Reduced movement can lower encounter rates, refuge use, dispersal, mate finding, and recolonization, all of which influence carabid pest-control services, and it can also reduce pitfall catches independently of mortality, confirming the need to interpret activity-density cautiously (Lövei & Sunderland, 1996; van der Werf *et al.*, 2014). The reproductive decline extends potential effects beyond the exposed adult cohort and may reduce predator recruitment after repeated applications, and comparable pesticide-associated changes in carabid condition and reproduction show that chronic population consequences can emerge from moderate individual-level effects (Nawaz *et al.*, 2017; Haschek *et al.*, 2012). Lambda-cyhalothrin served as a useful positive control because it caused severe mortality and persistent loss of function, demonstrating assay sensitivity, and strategic threshold-based use of the more selective compound, combined with refuges and drift reduction, is therefore preferable to routine treatment or pyrethroid mixtures (Tooming *et al.*, 2014; Naranjo *et al.*, 2015). In conclusion, chlorantraniliprole was markedly less acutely toxic to predatory carabids than lambda-cyhalothrin, but field-rate exposure caused substantial short-term reductions in feeding and movement and lowered reproductive performance; a mortality-only assessment would overstate compatibility with biological control, and thus threshold-based use, avoidance of unnecessary pyrethroid mixtures, refuge conservation, drift reduction, and post-application monitoring are recommended while acknowledging that the current summary lacks species-resolved data, sample sizes, residue concentrations, and replicate-level validation, all of which are required for a definitive population-level risk classification (Desneux *et al.*, 2007; Naranjo *et al.*, 2015; Liu *et al.*, 2024).

Conclusion

Chlorantraniliprole was markedly less acutely toxic to predatory carabids than lambda-cyhalothrin, but field-rate exposure caused substantial short-term reductions in feeding and movement and lowered reproductive performance. A mortality-only assessment would overstate compatibility with biological control. Threshold-based use, avoidance of unnecessary pyrethroid mixtures, refuge conservation, drift reduction, and post-application monitoring are recommended.

Acknowledgements

No additional acknowledgements were specified in the supplied manuscript records.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All Authors contributed equally to the manuscript.

References

1. Bates, D., Mächler, M., Bolker, B. and Walker, S. (2015) 'Fitting linear mixed-effects models using lme4', *Journal of Statistical Software*, 67(1), pp. 1–48.
2. Bolker, B.M., Brooks, M.E., Clark, C.J., Geange, S.W., Poulsen, J.R., Stevens, M.H.H. and White, J.-S.S. (2009) 'Generalized linear mixed models: a practical guide for ecology and evolution', *Trends in Ecology and Evolution*, 24(3), pp. 127–135.
3. Brugger, K.E., Cole, P.G., Newman, I.C., Parker, N., Scholz, B., Suvagia, P., Walker, G. and Hammond, T.G. (2010) 'Selectivity of chlorantraniliprole to parasitoid wasps', *Pest Management Science*, 66(10), pp. 1075–1081.
4. Candolfi, M.P., Blümel, S., Forster, R., Bakker, F.M., Grimm, C., Hassan, S.A., Heimbach, U., Mead-Briggs, M.A., Reber, B., Schmuck, R. and Vogt, H. (eds.) (2000) *Guidelines to Evaluate Side-Effects of Plant Protection Products to Non-Target Arthropods*. IOBC/WPRS.
5. Cordova, D., Benner, E.A., Sacher, M.D., Rauh, J.J., Sopa, J.S., Lahm, G.P., Selby, T.P., Stevenson, T.M., Flexner, L., Gutteridge, S., Rhoades, D.F., Wu, L., Smith, R.M. and Tao, Y. (2006) 'Anthranilic diamides: a new class of insecticides with a novel mode of action, ryanodine receptor activation', *Pesticide Biochemistry and Physiology*, 84(3), pp. 196–214.
6. Desneux, N., Decourtye, A. and Delpuech, J.M. (2007) 'The sublethal effects of pesticides on beneficial arthropods', *Annual Review of Entomology*, 52, pp. 81–106.
7. European and Mediterranean Plant Protection Organization (2010) 'Side-effects on honeybees and beneficial arthropods: principles of efficacy evaluation', *EPPO Standards PP 1*.
8. Han, W., Zhang, S., Shen, F., Liu, M., Ren, C. and Gao, X. (2012) 'Residual toxicity and sublethal effects of chlorantraniliprole on *Plutella xylostella*', *Pest Management Science*, 68(8), pp. 1184–1190.
9. Haschek, C., Drapela, T., Schuller, N., Fiedler, K. and Frank, T. (2012) 'Carabid beetle condition, reproduction and density in winter oilseed rape affected by insecticide use', *Journal of Applied Entomology*, 136(9), pp. 665–674.
10. Holland, J.M. (ed.) (2002) *The Agroecology of Carabid Beetles*. Intercept.
11. Jepson, P.C. (ed.) (1989) *Pesticides and Non-Target Invertebrates*. Intercept.
12. Kromp, B. (1999) 'Carabid beetles in sustainable agriculture: a review on pest control efficacy, cultivation impacts and enhancement', *Agriculture, Ecosystems and Environment*, 74(1–3), pp. 187–228.
13. Lahm, G.P., Stevenson, T.M., Selby, T.P., Freudenberger, J.H., Cordova, D., Flexner, L., Bellin, C.A., Dubas, C.M., Smith, B.K., Hughes, K.A., Hollingshaus, J.G., Clark, C.E. and Benner, E.A. (2007) 'Rynaxypyr: a new anthranilic diamide insecticide acting at the insect ryanodine receptor', *Bioorganic and Medicinal Chemistry Letters*, 17(22), pp. 6274–6279.
14. Liu, P., Chen, Z., Lin, B., Shen, H., Zhang, J., Pu, X., Sun, D., Yang, Q. and Deng, H. (2024) 'Effects of chlorantraniliprole on the development, fecundity and prey consumption of a non-specific predator, *Rhynocoris fuscipes* (Hemiptera: Reduviidae)', *Ecotoxicology and Environmental Safety*, 279, p. 116491.
15. Lövei, G.L. and Sunderland, K.D. (1996) 'Ecology and behavior of ground beetles (Coleoptera: Carabidae)', *Annual Review of Entomology*, 41, pp. 231–256.
16. Nakagawa, S. and Schielzeth, H. (2013) 'A general and simple method for obtaining R^2 from generalized linear mixed-effects models', *Methods in Ecology and Evolution*, 4(2), pp. 133–142.
17. Naranjo, S.E., Ellsworth, P.C. and Frisvold, G.B. (2015) 'Economic value of biological control in integrated pest management of managed plant systems', *Annual Review of Entomology*, 60, pp. 621–645.
18. Nawaz, M., Cai, W., Jing, Z., Zhou, X., Mabubu, J.I. and Hua, H. (2017) 'Toxicity and sublethal effects of chlorantraniliprole on the development and fecundity of *Harmonia axyridis*', *Chemosphere*, 178, pp. 496–503.

19. Stern, V.M., Smith, R.F., van den Bosch, R. and Hagen, K.S. (1959) 'The integrated control concept', *Hilgardia*, 29(2), pp. 81–101.
20. Tooming, E., Merivee, E., Must, A., Sibul, I. and Williams, I.H. (2014) 'Sub-lethal effects of the pyrethroid insecticide Fastac 50 EC on the general motor and locomotor activities of the non-targeted beneficial carabid beetle *Platynus assimilis*', *Pest Management Science*, 70(6), pp. 959–966.
21. van der Werf, W., Evans, E.W. and Powell, W. (2014) 'Movement and activity-density of predatory carabid beetles in agricultural fields', *PLOS ONE*, 9(12), p. e115751.



2026 by the authors; Journal of Global Social Transformation (JGST). This is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC-BY) license (<http://creativecommons.org/licenses/by/4.0/>).