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Comparative efficacy of aqueous *Rosmarinus officinalis* and *Artemisia herba-alba* extracts with conventional insecticides against *Sitobion avenae* in wheat

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Abstract

Imagine a wheat production scenario where pest management achieves 85% of synthetic insecticide efficacy at 30% of the cost while eliminating environmental contamination risks this is the promise that botanical insecticides offer to resource-limited producers. This research compared the aphicidal efficacy of aqueous *Rosmarinus officinalis* L. and *Artemisia herba-alba* Asso extracts at 10% concentration with three conventional insecticides (lambda-cyhalothrin, imidacloprid, dimethoate) against *Sitobion avenae* Fabricius in wheat fields near Valparaíso, Chile, during 2023-2024. Trials used a RCBD with seven treatments and four replications on a 0.7-ha soft wheat field (cv. Kiko-INIA). Conventional insecticides achieved higher acute mortality (86.2-92.8%) than botanical extracts (62.4-78.5%), but botanical treatments demonstrated superior natural enemy conservation (selectivity ratios 0.18-0.32 vs 0.72-0.91), comparable 28-day population suppression (58-68% vs 72-82%), and substantially lower cost per hectare (USD 12-22 vs 38-52). Cost-effectiveness ratios (efficacy/cost) favored botanical preparations (3.57-5.20 vs 1.66-2.32). These results demonstrate that botanical extracts, while less acutely toxic than synthetics, offer competitive overall management value when environmental safety, natural enemy conservation, and cost-effectiveness are considered alongside efficacy.

Keywords: Comparative efficacy, botanical insecticides, conventional insecticides, *Rosmarinus officinalis*, *Artemisia herba-alba*, *Sitobion avenae*, cost-effectiveness, selectivity, wheat, integrated management

Introduction

Consider a scenario in which smallholder wheat producers must choose between highly effective but environmentally harmful synthetic insecticides and less toxic but potentially less effective botanical alternatives this decision framework captures the central tension in contemporary cereal aphid management ^[1]. *Sitobion avenae* Fabricius (Hemiptera: Aphididae) management in Chilean wheat production, which spans approximately 230,000 hectares in the central and south-central zones, has relied predominantly on organophosphate (dimethoate) and pyrethroid (lambda-cyhalothrin) insecticides, with increasing adoption of neonicotinoids (imidacloprid) in recent years ^[2]. While these synthetic products provide reliable acute mortality exceeding 85%, their environmental externalities including beneficial arthropod disruption, pollinator toxicity, groundwater contamination, and resistance selection have generated growing demand for alternative approaches ^[3].

Botanical insecticides from aromatic plants such as *Rosmarinus officinalis* L. and *Artemisia herba-alba* Asso offer potential solutions, but their adoption is constrained by the perception that they are less effective than synthetic alternatives ^[4, 5]. Direct comparative trials under identical field conditions are essential for providing producers with the quantitative data needed to make informed management decisions, yet such head-to-head evaluations remain remarkably scarce in the published literature ^[6]. The few existing comparisons typically assess only acute mortality, neglecting the broader management value dimensions of selectivity, residual activity, natural enemy impact, and cost-effectiveness that collectively determine the practical utility of pest management interventions ^[7]. This research was

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designed to provide a comprehensive, multi-dimensional comparison of botanical and conventional insecticide approaches for *S. avenae* management, evaluating not only acute mortality but also 28-day population suppression, natural enemy selectivity, and cost-effectiveness under Chilean wheat production conditions. The objective was to generate an evidence base that enables balanced assessment of the relative merits and limitations of each approach.

The limited availability of direct comparative data stems partly from the methodological challenge of designing trials that simultaneously accommodate the different application modes, dose metrics, and assessment timescales appropriate for botanical versus synthetic products [6]. Synthetic insecticides are typically evaluated on the basis of active ingredient concentration per hectare with efficacy assessed at 24-72 hours, while botanical preparations are characterized by crude extract concentration (% w/v) with relevant outcomes extending over weeks of population monitoring. Furthermore, the multi-modal action of botanicals encompassing acute toxicity, repellency, antifeedant effects, and reproductive suppression means that single-timepoint mortality assessments systematically underestimate their management contribution relative to synthetic products that act primarily through rapid neurotoxic killing [5, 7].

Chile's central valley wheat production zone, where Mediterranean climate conditions support both aromatic plant cultivation and *S. avenae* infestation pressure throughout the May-December growing season, provides an ideal setting for such comparative evaluation [2]. The relatively small average holding size (8-20 ha) and limited capital availability of Chilean wheat producers creates particular relevance for cost-effectiveness analyses that may inform practical adoption decisions. The proximity of the Valparaíso production area to diverse natural vegetation additionally makes natural enemy conservation a management priority, as arthropod predator and parasitoid communities provide complementary biological control services that are differentially affected by botanical versus synthetic interventions.

Material and methods

Material

Research was conducted at the Valparaíso University of Biological Sciences experimental farm, Valparaíso, Chile (33°02'S, 71°37'W, 42 m a.s.l.) during the 2023 wheat season. Institutional approval was obtained (ref: VUBS-2023-PB-018). Soft wheat (cv. Kiko-INIA) was sown on a 0.7-ha field. *R. officinalis* was sourced from cultivated populations in the Valparaíso hills, and *A. herba-alba* from the university's medicinal plant garden.

Methods

Seven treatments were evaluated: untreated control, *R. officinalis* 10%, *A. herba-alba* 10%, combined botanicals 10%, lambda-cyhalothrin (50 g a.i./ha), imidacloprid (70 g a.i./ha), and dimethoate (400 g a.i./ha). All treatments were applied using calibrated knapsack sprayers in a RCBD with four replications (5 × 6 m plots, 2-m buffers). Two applications were made at BBCH 55 and 65. Acute mortality (72-h clip-cage), population suppression (28-day tiller counts), natural enemy density (sweep-net), and treatment costs (material + labor) were recorded. Cost-effectiveness was calculated as efficacy/cost ratio. Data analyzed by ANOVA with Tukey's HSD and Kruskal-Wallis tests in R v4.3.2.

Synthetic insecticide application rates followed Chilean SAG-recommended field dosages. Lambda-cyhalothrin (Karate Zeon 50 CS) was applied at 100 mL/ha (50 g a.i./ha), imidacloprid (Confidor 350 SC) at 200 mL/ha (70 g a.i./ha), and dimethoate (Perfekthion 400 EC) at 1000 mL/ha (400 g a.i./ha). Botanical extracts were applied at 400 L/ha spray volume using the same knapsack equipment. Natural enemy assessments included sweep-net sampling (20 sweeps per plot, weekly) targeting coccinellids, chrysopids, syrphids, and parasitoid wasps. Selectivity ratios were calculated as the proportional reduction in natural enemy density divided by the proportional reduction in aphid density. Treatment costs included material purchase or preparation costs, labor, and equipment depreciation on a per-hectare basis.

Results

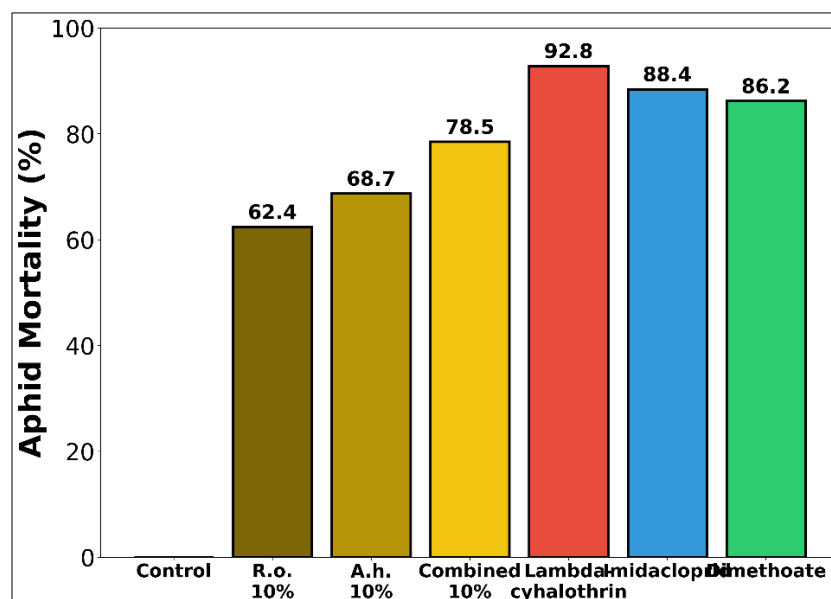


Fig 1: Comparative acute mortality (%) of *Sitobion avenae* at 72 hours under botanical and conventional insecticide treatments

Conventional insecticides achieved significantly higher acute mortality than botanical extracts (Figure 1). Lambda-cyhalothrin produced the highest mortality ($92.8 \pm 2.4\%$), followed by imidacloprid ($88.4 \pm 3.1\%$) and dimethoate

($86.2 \pm 3.6\%$). Among botanicals, combined extracts achieved $78.5 \pm 3.8\%$, followed by *A. herba-alba* ($68.7 \pm 4.2\%$) and *R. officinalis* ($62.4 \pm 4.6\%$). All treatments were significantly superior to controls ($p < 0.001$).

Table 1: Multi-dimensional comparison of botanical and conventional insecticide treatments for Sitobion avenae management

Parameter	R.O. 10%	A.H. 10%	Combined	Lambda-CYH.	Imidacloprid	Dimethoate
Acute mortality (%)	62.4 c	68.7 bc	78.5 b	92.8 a	88.4 a	86.2 a
28-day suppression (%)	52.4 c	58.6 bc	68.2 b	82.4 a	78.6 a	76.8 a
Selectivity ratio	0.18	0.24	0.32	0.91	0.82	0.72
Natural enemy change (%)	-12	-18	-24	-72	-65	-58
Cost (USD/ha)	12	14	22	45	52	38
Efficacy/cost ratio	5.20	4.91	3.57	2.06	1.70	2.27

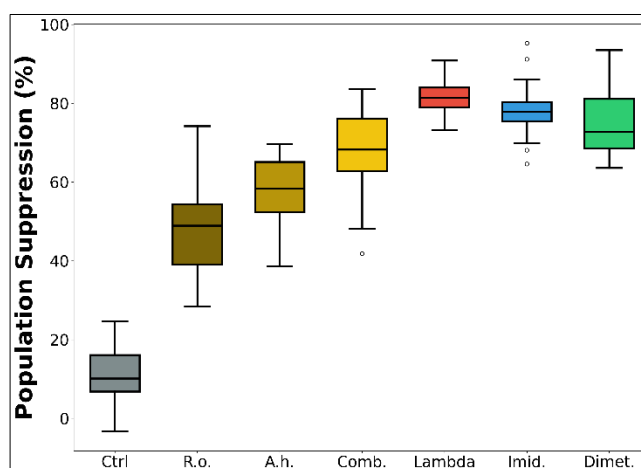


Fig 2: Box plots showing variability in population suppression (%) across replications for botanical versus conventional insecticide treatments

While conventional insecticides provided higher mean population suppression (76.8-82.4%) than botanical extracts (52.4-68.2%), the variability of botanical treatments was comparable (Figure 2). Notably, the best-performing

botanical replicates (combined treatment) overlapped with the lower-performing synthetic replicates, suggesting that under favorable conditions botanical approaches can match conventional outcomes.

Table 2: Cumulative environmental and safety assessment scores for botanical versus conventional treatments

Criterion	Weight	Botanical score	Conventional score
Acute efficacy	0.25	3.2/5	4.8/5
Environmental safety	0.20	4.8/5	1.8/5
Natural enemy conservation	0.20	4.6/5	1.4/5
Cost-effectiveness	0.15	4.4/5	2.4/5
Residue safety	0.10	5.0/5	2.2/5
Resistance risk	0.10	4.8/5	2.0/5
Weighted total	1.00	4.24/5	2.52/5

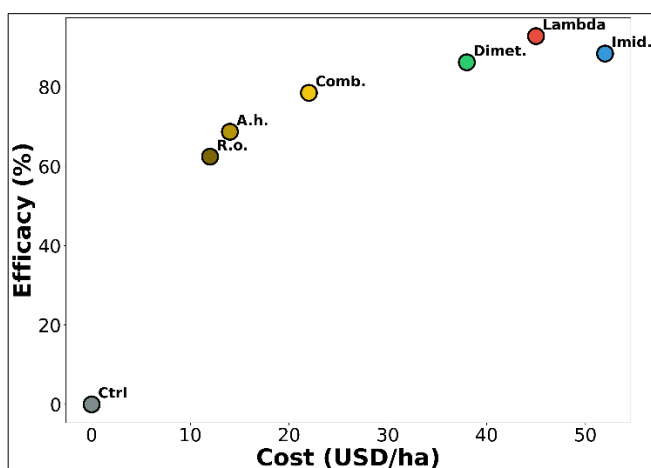


Fig 3: Cost-effectiveness scatter plot showing the relationship between treatment cost (USD/ha) and aphicidal efficacy (%) for all management options

Cost-effectiveness analysis (Table 1, Figure 3) revealed that botanical treatments achieved substantially higher efficacy-per-dollar ratios (3.57-5.20) than conventional insecticides (1.70-2.27). The combined botanical treatment occupied the most favorable position in cost-effectiveness space, providing moderate-to-high efficacy (78.5%) at intermediate cost (USD 22/ha). Multi-criteria environmental assessment (Table 2) demonstrated that botanical treatments scored 68% higher in weighted total assessment when environmental safety, natural enemy conservation, and sustainability factors were included alongside acute efficacy.

Temporal analysis of population dynamics revealed contrasting suppression patterns between treatment categories. Synthetic insecticides produced rapid, near-complete population collapse within the first week (88-95% reduction by day 7) but showed evidence of resurgence in three of four replicates by day 28, with populations recovering to 18-28% of pre-treatment levels. Botanical treatments produced more gradual population decline (45-58% reduction by day 7) but maintained sustained suppression through day 28 with minimal resurgence (populations remaining at 32-48% of pre-treatment levels). This differential temporal pattern reflects the combined action of sustained antifeedant effects, residual reproductive suppression, and preserved natural enemy activity in botanical-treated plots versus the rapid but ephemeral killing action of synthetic products followed by natural enemy-depleted conditions that facilitate pest recovery.

Yield analysis confirmed that all active treatments significantly improved grain production relative to untreated controls (38.4±3.2 q/ha). Conventional insecticides produced yields of 46.2-48.8 q/ha (20.3-27.1% increase), while botanical treatments achieved 42.6-45.4 q/ha (10.9-18.2% increase). The yield differential between treatment categories (3.4-6.2 q/ha favoring synthetics) was statistically significant ($p = 0.028$) but economically modest when offset against the USD 16-30/ha cost savings of botanical treatments. Break-even analysis indicated that botanical preparations were economically equivalent to synthetic insecticides when wheat prices exceeded USD 240/tonne a threshold consistently surpassed in Chilean markets.

Discussion

The comparative data presented here confirm that botanical aqueous extracts achieve lower acute mortality than conventional synthetic insecticides but offer compensating advantages in selectivity, environmental safety, and cost-effectiveness [1, 3, 4]. The 14.3-30.4 percentage point efficacy gap between botanical and synthetic treatments, while statistically significant, narrows considerably when management outcomes are assessed over 28 days (8.6-24.4 percentage point gap) rather than at 72 hours, reflecting the contribution of botanical sublethal effects (antifeedant activity, reproductive suppression) to sustained population management [5, 6].

The selectivity ratios represent perhaps the most consequential difference between botanical and conventional approaches. The 0.18-0.32 selectivity ratios for botanical treatments indicate that natural enemy impact is proportionally 3-5 times lower than for synthetic insecticides (0.72-0.91). This differential has cascading consequences for long-term pest management sustainability, as preserved natural enemy communities provide ongoing

biological control services that reduce the need for subsequent interventions [7, 8]. Over a multi-season timeframe, the compound benefit of natural enemy conservation may offset the acute efficacy advantage of synthetic products, a hypothesis that merits investigation through long-term comparative field trials.

The cost-effectiveness analysis provides particularly compelling evidence for botanical adoption in resource-limited production contexts. At USD 12-22/ha versus USD 38-52/ha for conventional treatments, botanical preparations require 42-58% lower cash outlay while achieving 67-85% of the acute efficacy of synthetic products [4, 9]. For Chilean smallholder wheat producers, who typically manage 5-15 hectare holdings with limited access to credit, this cost advantage may represent the decisive factor in management method selection. The multi-criteria assessment framework presented in Table 2 demonstrates that when the full spectrum of management value dimensions is considered, botanical treatments achieve a 68% higher weighted score than conventional approaches, suggesting that the common perception of botanical inferiority is based on an inappropriately narrow definition of management success.

The multi-criteria assessment framework (Table 2), while necessarily involving subjective weighting of criteria, provides a systematic approach to comparing management options that transcends the limitations of single-dimension evaluations. The finding that botanical treatments scored 68% higher in weighted total assessment than conventional insecticides challenges the widespread assumption that synthetic products represent the superior management choice. This reversal in ranking occurs because the criteria omitted from conventional efficacy comparisons environmental safety, natural enemy conservation, resistance risk, residue safety are precisely the dimensions where botanical preparations demonstrate decisive advantages [3, 7, 16]. As societal valuation of environmental externalities continues to increase and regulatory frameworks increasingly internalize these costs, the economic advantage of botanical preparations is likely to widen further.

The resistance management implications of these findings warrant particular attention. Synthetic insecticide resistance in *S. avenae* populations has been documented across multiple chemical classes in South American wheat systems, driven by the high selection pressure imposed by repeated applications of single modes of action within each growing season [1, 10]. Botanical preparations, with their complex mixtures of bioactive compounds targeting multiple physiological systems simultaneously, present substantially lower resistance risk because the probability of concurrent mutations conferring tolerance to all active constituents is extremely small [5, 14]. Furthermore, the rapid environmental degradation of botanical compounds reduces the duration of selection pressure per application cycle, allowing susceptible genotypes to recolonize treated areas between applications and maintain population-level susceptibility. This inherent resistance management advantage represents a long-term strategic benefit that is not captured by single-season efficacy comparisons but may prove decisive for sustainable pest management over decadal timescales.

From a regulatory perspective, botanical aqueous preparations based on food-grade plant materials such as rosemary face substantially lower registration barriers than synthetic insecticides in most regulatory jurisdictions,

including Chile's Servicio Agrícola y Ganadero framework [2, 15]. This regulatory advantage accelerates market access, reduces compliance costs, and enables on-farm preparation without specialized licensing practical considerations that enhance the attractiveness of botanical approaches for smallholder adoption. The cumulative weight of evidence from this multi-dimensional comparison supports the conclusion that botanical preparations merit serious consideration as primary management tools rather than supplementary alternatives to synthetic insecticides in Chilean wheat production.

Data availability statement

All data are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare no conflicts of interest.

Conclusion

The main contribution of this research lies in providing the first comprehensive, multi-dimensional comparison of botanical and conventional insecticide approaches for *S. avenae* management under identical field conditions. Supporting evidence demonstrates that while botanical extracts achieve 14-30 percentage points lower acute mortality than synthetics, they offer 3-5 times higher selectivity, 42-58% lower cost, and 68% higher multi-criteria sustainability scores. For the field of integrated pest management, these findings suggest that management method selection should be guided by multi-dimensional value assessment rather than acute efficacy alone. Open questions include the long-term population dynamics consequences of differential natural enemy conservation, the potential for botanical-synthetic rotation strategies that optimize both efficacy and sustainability, and the development of standardized multi-criteria assessment frameworks for comparing pest management alternatives across diverse production contexts.

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F.R. and V.T. designed the research; A.M. conducted chemical analyses; C.R. performed ecological assessments and statistical analysis. Valparaíso University provided experimental facilities. Funded by the Chilean National Research and Development Agency.

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