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Efficacy of Aqueous Plant Extracts in the Control of Downy Mildew (*Peronospora variabilis*) in Quinoa (*Chenopodium quinoa*)

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Abstract

Downy mildew caused by *Peronospora variabilis* is one of the main health problems affecting quinoa cultivation in the Andean region. The objective of this study was to evaluate the efficacy of aqueous extracts of garlic (*Allium sativum*), horsetail (*Equisetum bogotense*), and paico (*Chenopodium ambrosioides*) in reducing the severity of downy mildew and its effect on the yield of the Blanca Junín and Pasankalla quinoa varieties. The working solutions contained 10% of the crude extract. Foliar applications were made every 7 days, between 21 and 84 days after sowing. Using a randomized complete block split-plot design, severity, area under the disease progress curve (AUDPC), and relative efficacy (RE) of the treatment were quantified. The results revealed a significant interaction between variety and treatment ($p < 0.05$). Garlic extract in the Blanca Junín variety stood out as the best alternative for downy mildew control, considerably reducing AUDPC, increasing yield, and demonstrating greater RE (68.4%) compared to the synthetic fungicide metalaxyl. In the Pasankalla variety, because of its greater intrinsic tolerance, the impact of the extracts on yield was less pronounced. These findings position plant extracts, especially garlic extracts, as viable alternatives for the integrated management of downy mildew in quinoa crops, although it is recommended to validate their effectiveness in multiple campaigns that align with environmental sustainability and human health.

Keywords: botanical extracts; effective biofungicides; genotypic response; oomycete control; organosulfur compounds

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INTRODUCTION

Quinoa (*Chenopodium quinoa*) has transcended its Andean origins to become a globally important crop (Bazile et al., 2015), recognized for its exceptional nutritional quality. Its grains are characterized by a high protein content (12 to 18%), a balanced profile of essential amino acids, particularly lysine, and the presence of minerals, vitamins, and bioactive compounds such as flavonoids (Christensen et al., 2007; Vega-Gálvez et al., 2010; Pathan and Siddiqui, 2022). This growing interest has been further strengthened in the context of climate change, given quinoa's importance as a traditional crop cultivated by small-scale farmers in the Andes (Bazile, 2024).

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Quinoa has a remarkable capacity to produce under abiotic stress conditions and in marginal soils (Ruiz et al., 2014). However, the expansion and importance of quinoa are directly threatened by its high vulnerability to diseases. In particular, downy mildew caused by *Peronospora variabilis* remains the main health constraint for the crop (Danielsen et al., 2002). Susceptibility to this pathogen leads to significant losses that compromise production stability and profitability, underscoring the need to research and develop sustainable management alternatives.

Quinoa downy mildew is caused by the oomycete *P. variabilis*, a biotrophic pathogen (Colque-Little et al., 2021). This infects the mesophyll of the leaves, causing chlorosis, wrinkling, and a characteristic grayish mycelial growth on the underside of the leaves, drastically reducing the plant's photosynthetically active area (Danielsen and Ames, 2008; Colque-Little et al., 2021). Favorable environmental conditions, specifically high relative humidity and temperatures between 15 and 20 °C, accelerate the progression of the epidemic. This typically leads to premature defoliation and severe yield losses between 40% and 100% (Danielsen and Ames, 2008).

Conventional control relies almost exclusively on synthetic contact fungicides (e.g., chlorothalonil) and systemic fungicides (e.g., metalaxyl). However, the use of these fungicides poses health risks to the environment and humans (Danielsen et al., 2003), including phytotoxicity, elimination of beneficial fauna, contamination of aquifers, and toxic residues in grain, thereby compromising product safety. There is also the risk that the pathogen may develop resistance to metalaxyl, as has been demonstrated in the case of *Phytophthora infestans* in another Andean crop, such as potato (Gisi and Cohen, 1996).

In various Andean communities in Peru, where small-scale farmers practice low-input agriculture, the use of plant extracts with medicinal properties to control diseases is common (Pando and Aguilar, 2016). These extracts include garlic (*Allium sativum*), horsetail (*Equisetum bogotense*), and paico (*Chenopodium ambrosioides*), which are biodegradable and environmentally friendly. These practices have been passed down through generations, based on empirical observation and the availability of local resources (Apaza Ticona et al., 2022). In quinoa crops, these extracts are used especially in local varieties like Pasankalla, which is prevalent in subsistence farming systems.

However, the lack of scientific studies standardizing dosages, application times, and actual efficacy limits their formal adoption in the management of *P. variabilis*. The instability of chemical components and oscillations in the concentrations of bioactive metabolites in traditional preparations hinder their reproducibility under experimental conditions, which generates fluctuations in therapeutic efficacy (Sanjai et al., 2024). This study underscores the need to rigorously validate this traditional agricultural practice under controlled conditions in an experimental field, including the Blanca Junín variety typical of conventional systems, to determine whether the response to treatments depends on genotype or cultivation system.

Aqueous plant extracts owe their antifungal capacity to the presence of secondary metabolites such as organosulfur compounds, essential oils, terpenoids, saponins, flavonoids, and phenols. These metabolites can be extracted using conventional and non-conventional techniques to formulate biofungicides (Cenobio-Galindo et al., 2024). Garlic contains allicin, a broad-spectrum organosulfur compound whose mechanism of action is based on the alteration of cell membranes, inhibition of key enzymes, and generation of oxidative stress in fungi and oomycetes (Slusarenko et al., 2008; Fufa, 2019; Sarfraz et al., 2020).

Horsetail is rich in silica, a substance that contributes to the structural reinforcement of plant tissues and induces defense responses such as the accumulation of phytoalexins and increased lignification (Sandhu et al., 2010; Makia et al., 2022; Sureshkumar, 2023). These responses strengthen cell walls and induce defense responses that hinder pathogen penetration (Wang et al., 2017). Paico contains ascaridol and other oxygenated monoterpenes with potent antimicrobial and fungicidal activity, demonstrated in the control of various agricultural pathogens (Jaramillo et al., 2012; Langsi et al., 2017). Furthermore, horsetail exhibits a broad spectrum of fungicidal and antibacterial activity against various plant pathogens (Kumar et al., 2007; Shah, 2014; Wei et al., 2024). This biological basis supports the hypothesis that extracts can interfere with both the germination of *P. variabilis* spores and the progression of lesions on the leaves of infected plants.

Scientific literature reports that garlic extracts inhibit the growth of pathogens such as *Phytophthora capsici*, *Fusarium oxysporum*, and

Alternaria solani (Li and Zhihui, 2008; Hayat et al., 2016; Roy et al., 2019). Extracts of horsetail have been successfully used to control the production of mycotoxins and other mycotoxigenic fungi in stored cereals and fruits, the presence of *Aspergillus* and *Fusarium* in stored corn, and the effects of *P. infestans* on organic tomato crops (Da Cruz Cabral et al., 2013; García et al., 2013; Trebbi et al., 2021). Furthermore, extracts of paico have shown efficacy against pathogens of stored crop products, including *Sitotroga cerealella*, *Sitophilus granarius*, and *Sitophilus zeamais* (Kumar et al., 2007; Jaramillo et al., 2012; Langsi et al., 2017), suggesting a broad potential for application.

At the same time, genetic studies reveal that ecogeographic origin, saponin content, and morphophysiological characteristics greatly influence the susceptibility of different quinoa cultivars to downy mildew (Testen et al., 2014; Colque-Little et al., 2021). These differences justify comparing the Blanca Junín and Pasankalla varieties under the same treatments to determine whether the effect of the extracts is stable across genotypes or depends on varietal background.

Despite the widespread use of aqueous plant extracts in Andean family farming, there are no quantitative, controlled, and replicated studies evaluating the specific efficacy of aqueous extracts of garlic, horsetail, and paico against *P. variabilis* under real field conditions. Most existing research focuses on other crops or pathogens, while evaluations with quinoa remain scarce and poorly standardized (Rubén et al., 2015). Furthermore, it is unknown whether the response to these aqueous extracts depends on the quinoa variety, a critical gap considering the crop's wide genetic diversity. This study seeks to fill this gap by providing consistent experimental evidence to support the formal use of these alternatives within integrated downy mildew management in agroecological and conventional systems.

Therefore, the objective of this study was to evaluate and quantify the effectiveness of aqueous extracts of garlic, horsetail, and paico in controlling downy mildew caused by *P. variabilis* in the quinoa varieties Blanca Junín and Pasankalla. Specifically, the study assessed their effects on disease incidence and severity and generated evidence to support the integration of these practices into sustainable sanitary management strategies.

MATERIALS AND METHOD

Study focus

The research was developed under a quantitative approach to evaluate the antifungal efficacy of aqueous extracts of *A. sativum*, *E. bogotense*, and *C. ambrosioides* in the control of *P. variabilis* in *C. quinoa* crops.

Location and weather conditions

The experiment was conducted at the Experimental Center of the National University of San Cristóbal de Huamanga, located in Ayacucho, Peru, at 74°32'00" W and 13°08'05" S, at an altitude of 2,750 m above sea level. During the experimental period, the average temperature was 18.52 °C, with minimum and maximum values of 11.09 and 25.85 °C, respectively. Average rainfall of 62.90 mm and an average relative humidity of 74.6% were also recorded, conditions favorable for the natural development of downy mildew.

Varieties evaluated

Two quinoa varieties with contrasting phytosanitary behavior against *P. variabilis* were used: Blanca Junín and Pasankalla. Blanca Junín, a sweet ecotype from the inter-Andean valleys with low saponin content (Danielsen and Ames, 2008). It exhibits intermediate susceptibility to downy mildew, potentially experiencing significant yield losses (up to 50% or more) under high disease pressure (Colque-Little et al., 2021). Pasankalla, on the other hand, a high-altitude variety with high saponin content, shows greater tolerance or resistance to the pathogen (Pérez, 2005; Danielsen and Ames, 2008; Estrada-Zúniga et al., 2022). The selection of both varieties allowed for the evaluation of treatment efficacy under different levels of genetic susceptibility.

Preparation of extracts

The concentrated aqueous extract of *A. sativum* was prepared using 100 g of fresh, healthy bulbs, previously peeled and mechanically crushed to promote the release of bioactive sulfur compounds, primarily allicin. Subsequently, the crushed material was mixed with 1 l of chlorine-free water and subjected to cold maceration for 24 hours in the dark. After the extraction period, the mixture was filtered through a fine cloth to obtain the crude extract (Singh, 2008).

The concentrated aqueous extract of *E. bogotense* was prepared using 100 g of finely ground dried biomass, macerated in 1 l of

chlorine-free water for 14 days. The mixture was stirred periodically to promote the solubilization of the active metabolites. After the extraction period, the contents were filtered through a fine cloth to obtain the crude extract (Singh, 2008).

The concentrated aqueous extract of *C. ambrosioides* was prepared using 200 g of fresh leaves and stems, previously washed and cut into small fragments. The plant material was macerated in 1 l of chlorine-free water for 4 days, with periodic stirring. Subsequently, the mixture was filtered through a fine cloth to obtain the crude extract (Singh, 2008).

The working solutions were prepared with the following dilutions: *A. sativum* extract at a ratio of 1:20 (v/v), *E. bogotense* and *C. ambrosioides* extracts at a ratio of 1:10 (v/v), and metalaxyl (Fitoklin) at a rate of 2 g per 20 l of water, according to the manufacturer's recommendations. All solutions incorporated an adhering agent prepared by dissolving 100 g of neutral soap in 2 l of water.

Phytosanitary conditions

The experimental plot was selected due to a history of recurrent downy mildew (*P. variabilis*) infections observed during consecutive growing seasons. Oospores are transmitted through contaminated soil, a primary source of inoculum (Cruces, 2016). The endemic condition was confirmed through a preliminary phytosanitary inspection, microscopic identification of the pathogen, and an assessment of incidence and severity before the establishment of the experiment.

The seeds were selected and disinfected with 1% sodium hypochlorite before sowing (Fukuzaki, 2006; García-Torres et al., 2025) to eliminate external contaminants and to homogenize the initial conditions of the experiment, allowing the *P. variabilis* infection to come mainly from the natural inoculum present in the endemic plot.

Experimental design

The experiment was conducted using a randomized complete block design with split plots and 3 replications. The main factor was the quinoa variety, with 2 levels: Blanca Junín and Pasankalla. The second factor was the phytosanitary treatments, which consisted of 5 levels: negative control without extract (only water) (T0), *A. sativum* extract (T1), *E. bogotense* extract (T2), *C. ambrosioides* extract (T3), and positive control with Fitoklin (T4).

Each block consisted of 2 main plots corresponding to the varieties, within which the 5 experimental subplots were randomly distributed. In total, 30 experimental units were established (2 varieties × 5 treatments × 3 replicates). Each experimental unit consisted of 2 rows, with a total area of 12.8 m² and a usable area of 128 m². Plants were spaced 0.8 m apart between rows and 0.1 m apart within rows.

Application of treatments

The treatments were applied using a hand-held backpack sprayer at constant pressure. Applications began when the plants reached the phenological stage with 4 to 6 true leaves. Ten applications were made at 7-day intervals.

In each experimental unit, the solutions were sprayed uniformly onto both leaf surfaces (front and back) until runoff. The chemical treatment was applied following the product label recommendations and appropriate safety precautions.

Variables evaluated

Disease severity

Downy mildew severity was assessed weekly from 21 to 84 days after sowing (DAS). A categorical scale adapted from Danielsen and Ames (2008) was used, based on the percentage of affected leaf area: 0% = immune; 1 to 10% = very resistant; 11 to 25% = moderately resistant; 26 to 50% = moderately susceptible; and 51 to 100% = very susceptible. In each assessment, 10 plants were randomly selected from the area corresponding to each experimental unit, and the percentage of affected tissue on fully developed leaves was visually estimated. The area under the disease progress curve (AUDPC) was calculated from the data obtained, according to the methodology described by Simko and Piepho (2012) (Equation 1).

Agronomic variables

At the end of the crop cycle (physiological maturity), the following agronomic variables were evaluated: plant height (cm), panicle length (cm), panicle weight (g), and estimated yield (kg ha^{-1}). Yield was determined from the total production obtained in the usable area of each plot, following standardized methodologies for agronomic trials (Norman et al., 1995; Sud et al., 2017) (Equation 2).

Control efficacy (CE)

To determine the capacity of each treatment to reduce disease development in the crop,

$$\text{AUDPC} = \frac{\sum_{i}^{n-1}(y_i + y_{i+1})}{2 \times (t_{i+1} + t_i)} \quad (1)$$

$$\text{Yield}\left(\text{kg ha}^{-1}\right) = \frac{\text{Quantity produced}}{\text{Area harvested}} \times 100 \quad (2)$$

$$\text{CE}\ (\%) = \frac{\text{AUDPC}_{\text{Control}} - \text{AUDPC}_{\text{Treatment}}}{\text{AUDPC}_{\text{Control}}} \times 100 \quad (3)$$

the formula from Abbott (1925) was applied using the obtained AUDPC values (Equation 3).

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics version 26. Before the analysis of variance, the assumptions of normality of the residuals (Shapiro-Wilk test) and homogeneity of variances (Levene's test) were verified. The analysis of variance (ANOVA) was performed with the variety factor as a plot effect, the treatment factor as a subplot effect, and the variety × aqueous extract treatment interaction. When the ANOVA showed significant differences ($p < 0.05$), the means were compared using Tukey's HSD test for the factors and the interaction. In cases where the variety × aqueous extract treatment interaction was significant, the interpretation was performed within each variety, disaggregating the simple effects according to the design structure.

RESULTS AND DISCUSSION

Severity of downy mildew

Downy mildew severity showed a progressively increasing pattern up to 42 DAS, followed by a gradual decrease in both quinoa varieties (Table 1). In general, the Blanca Junín variety exhibited higher severity and AUDPC values compared to the Pasankalla, demonstrating greater susceptibility to *P. variabilis*.

Among the aqueous extracts evaluated, T1 showed the best performance, with significant reductions in severity starting at 49 DAS and an AUDPC of 1,617.7 in Blanca Junín and 1,555.3 in Pasankalla. The treatments T2 and T3 showed intermediate severity values, with a moderate reduction of the disease compared to the control. In T0, severity reached its maximum value at 42 DAS (45.8% in Blanca Junín and 39.3% in Pasankalla), remaining high until the end of the cycle and resulting in the highest AUDPC values (1,951.9 and 1,815.2, respectively). Treatment T4 significantly reduced severity at all evaluation dates after 42 DAS, reaching the lowest severity values at the last evaluation (84 DAS) and the lowest AUDPC.

The results obtained show that aqueous extracts of *A. sativum*, *E. bogotense*, and *C. ambrosioides* exert different effects on the progression of downy mildew caused by *P. variabilis* in the quinoa varieties Blanca Junín and Pasankalla. Overall, the reduction in severity and AUDPC indicates that the aqueous extract of *A. sativum* was the most effective among the treatments evaluated. However, the fungicide metalaxyl remained the most effective, as reported in the literature for the management of oomycetes in different crops (Hanson and Shattock, 1998; Kumar et al., 2007; Pánek et al., 2022).

The low standard deviations (SD) across most treatments and evaluation dates indicate low dispersion of the data around the mean, suggesting good homogeneity among the experimental replicates. This low variability reinforces the reliability of the results. It supports the idea that the observed differences between treatments reflect highly reliable effects of the plant extracts and the fungicide on downy mildew severity.

Effect of treatments on agronomic parameters

The use of aqueous plant extracts significantly influenced ($p < 0.05$) the yield and agronomic variables of both quinoa varieties (Table 2). The only exception was panicle length in the Pasankalla variety ($p = 0.189$), where no statistically significant differences were observed between treatments.

In the Blanca Junín variety, T1 showed the best performance, with significant increases in panicle weight (120 g) and yield (3,942 kg ha^{-1}) compared to the control, reaching statistically similar values to those of metalaxyl in these 2 variables. T2 and T3 showed intermediate results, with yield increases of 18.8% and 26.9% compared to the control, respectively, although their effectiveness remained lower than that of the treatment T4. In the Pasankalla variety, the T1 increased yield by 10.9% compared to the control (1,923 kg ha^{-1}),

Table 1. Downy mildew severity and AUDPC in quinoa varieties treated with aqueous plant extract were evaluated throughout the phenological cycle

Treatment	Variety	St.*	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS	63 DAS	70 DAS	77 DAS	84 DAS	AUDPC
T0	Blanca Junín	M	12.2^{a}	32.2^{a}	36.3^{a}	45.8^{a}	39.3^{a}	30.8^{a}	24.3^{a}	23.3^{a}	26.1^{a}	29.3^{a}	1,951.9^{a}
		SD	0.425	1.005	2.110	1.521	1.850	1.704	1.002	0.737	0.538	0.725	29.952
	Pasankalla	M	11.9^{a}	32.1^{a}	35.5^{a}	39.3^{a}	31.9^{a}	26.7^{a}	23.5^{a}	27.2^{a}	23.3^{a}	27.7^{a}	1,815.2^{a}
		SD	0.654	1.389	0.669	1.907	1.157	1.799	0.376	2.190	0.938	1.463	2.824
T1	Blanca Junín	M	12.4^{a}	33.4^{a}	33.4^{a}	39.7^{ab}	31.6^{b}	22.3^{b}	20.9^{bc}	18.6^{ab}	17.1^{b}	15.9^{b}	1,617.7^{bc}
		SD	0.895	0.165	6.185	2.498	1.998	0.952	0.928	2.134	1.733	0.392	86.936
	Pasankalla	M	12.1^{a}	32.1^{a}	34.0^{a}	37.0^{a}	27.8^{ab}	21.9^{b}	20.0^{a}	19.4^{b}	16.7^{bc}	14.5^{b}	1,555.3^{bc}
		SD	0.720	0.895	1.522	1.281	1.413	1.042	2.532	1.768	2.414	0.705	41.528
T2	Blanca Junín	M	12.3^{a}	32.6^{a}	35.6^{a}	40.2^{ab}	33.7^{ab}	24.6^{b}	21.6^{ab}	19.1^{a}	18.2^{b}	17.2^{bc}	1,682.4^{b}
		SD	0.462	1.250	1.807	5.006	3.941	1.568	0.659	3.108	1.656	1.927	83.084
	Pasankalla	M	12.5^{a}	33.5^{a}	32.1^{a}	38.6^{a}	30.4^{ab}	23.4^{b}	20.5^{a}	20.3^{b}	18.2^{ab}	15.7^{b}	1,617.5^{b}
		SD	0.176	0.697	4.614	4.322	0.421	0.340	1.827	1.071	1.743	0.709	33.687
T3	Blanca Junín	M	11.9^{a}	32.2^{a}	32.7^{a}	41.4^{ab}	35.7^{ab}	23.3^{b}	20.5^{bc}	20.6^{a}	18.8^{b}	19.2^{c}	1,685.2^{b}
		SD	0.696	0.440	2.835	7.047	1.266	2.072	1.760	2.202	0.736	2.174	37.124
	Pasankalla	M	11.3^{a}	31.6^{a}	33.8^{a}	37.2^{a}	26.4^{b}	22.0^{b}	19.2^{a}	20.1^{b}	20.1^{ab}	17.7^{b}	1,574.3^{bc}
		SD	0.497	1.419	0.182	1.668	3.346	0.768	3.113	3.109	1.159	1.720	64.495
T4	Blanca Junín	M	12.2^{a}	32.7^{a}	31.8^{a}	36.2^{b}	31.7^{b}	22.2^{b}	18.2^{c}	13.3^{b}	11.5^{c}	10.7^{d}	1,463.5^{c}
		SD	0.157	0.919	2.450	1.394	1.859	0.846	0.709	2.506	0.649	0.138	43.400
	Pasankalla	M	11.6^{a}	31.4^{a}	32.2^{a}	34.3^{a}	30.4^{ab}	21.0^{b}	19.3^{a}	13.1^{c}	11.4^{c}	11.0^{c}	1,430.3^{c}
		SD	0.261	0.697	2.306	1.807	0.503	0.790	5.059	2.302	4.971	0.092	84.550
p-value	Blanca Junín		0.833	0.512	0.379	0.019	0.006	0.000	0.002	0.002	0.000	0.000	0.000
	Pasankalla		0.147	0.290	0.543	0.568	0.033	0.001	0.408	0.000	0.002	0.000	0.000

Note: Different letters in the same column indicate a significant difference ($p < 0.05$) according to Tukey's test. T0 = Negative control without extract (only water); T1 = *A. sativum* extract; T2 = *E. bogotense* extract; T3 = *C. ambrosioides* extract; T4 = Positive control with fitoklin; St.* = Statistics; M = Mean; SD = Standard deviation

and did not differ statistically from metalaxyl in panicle weight. Treatments T2 and T3 showed smaller effects, although higher than T0, without reaching the levels of T1 or T4.

The reduction of disease does not always translate proportionally into yield gains. In this regard, several authors have pointed out that the relationship between downy mildew severity and yield loss in quinoa may not be linear, due to the crop's physiological plasticity, phenology, duration of stress, and capacity for recovery after early infections (Danielsen and Munk, 2004; Dalal et al., 2017). The concordance between reported biochemical mechanisms and the effectiveness of disease control mechanisms under field conditions reinforces the potential of *A. sativum* as a sustainable management alternative. The recorded SDs were low in most of the variables evaluated, indicating homogeneity between replicates and proper execution of the experiment, which adds reliability to the differences observed between treatments.

Control efficacy (CE) and relative efficacy (RE) of plant extracts

To evaluate treatment performance, 2 complementary metrics were calculated: CE and RE of plant extracts and metalaxyl on downy mildew progression (Table 3). CE was calculated using Abbott's formula (1925) relative to the absolute control (T0), thus expressing the percentage of the actual reduction in disease progression (AUDPC) attributable to each treatment. RE was also calculated, assigning a reference value of 100% to the metalaxyl treatment, in order to contextualize the performance of the plant extracts.

The results revealed a gradient of efficacy. In the Blanca Junín variety, the *A. sativum* extract registered the highest CE among the plant extracts (17.1%), which translated to an RE of 68.4%. This indicates that under the experimental conditions, *A. sativum* achieved approximately two-thirds of the disease-suppression capacity demonstrated by the chemical fungicide. The *E. bogotense* and *C. ambrosioides* extracts showed moderate and statistically similar efficacy, with REs of 55.2% and 54.6%, respectively. In the Pasankalla variety, a similar pattern was observed, though with slightly lower values, with *A. sativum* again standing out with a CE of 14.3% and RE of 67.5%.

An RE value of 68.4% for *A. satvum* should not be interpreted as meaning that this extract controls 68.4% of the disease that metalaxyl controls. Rather, it means that the magnitude of its contribution to controlling disease progression, relative to the maximum reduction achieved by metalaxyl, is 68.4%. This metric is particularly useful for agronomic decision-making, as it allows for weighing the potential of an alternative treatment against the chemical standard.

A key finding from these calculations is the moderate efficacy of metalaxyl. Despite being the most effective treatment, its CE was only 25.0% in Blanca Junín and 21.2% in Pasankalla. This result, far from indicating product failure,

Table 2. Effect of aqueous plant extracts on agronomic variables and yield according to the quinoa variety

Treatment	Statistic	Blanca Junín				Pasankalla			
		Plant height (cm)	Panicle height (cm)	Panicle weight (g)	Yield (kg ha^{-1})	Plant height (cm)	Panicle height (cm)	Panicle weight (g)	Yield (kg ha^{-1})
T0	M	186^{c}	78^{c}	100^{d}	2,764^{c}	134^{c}	54^{a}	68^{c}	1,734^{c}
	SD	1.11	0.47	1.24	99.97	1.22	2.07	1.47	2.36
T1	M	192^{b}	85^{ab}	120^{b}	3,942^{a}	143^{b}	58^{a}	78^{a}	1,923^{b}
	SD	2.83	1.51	1.57	75.05	3.16	1.55	1.35	113.14
T2	M	188^{bc}	82^{bc}	109^{c}	3,284^{b}	139^{bc}	56^{a}	72^{b}	1,751^{bc}
	SD	1.74	0.8	1.28	108.29	2.61	2.09	2.20	44.02
T3	M	190^{b}	84^{ab}	113^{c}	3,508^{b}	140^{bc}	57^{a}	76^{ab}	1,802^{bc}
	SD	1.44	1.31	2.32	135.55	2.03	1.77	1.20	47.31
T4	M	199^{a}	86^{a}	129^{a}	4,013^{a}	150^{a}	58^{a}	81^{a}	2,192^{a}
	SD	1.73	1.68	2.57	111.83	2.52	1.35	1.81	71.92
p-value		0.000	0.000	0.000	0.000	0.000	0.189	0.000	0.000

Note: Different letters in the same column indicate a significant difference ($p < 0.05$) according to Tukey's test. T0 = Negative control without extract (only water); T1 = *A. sativum* extract; T2 = *E. bogotense* extract; T3 = *C. ambrosioides* extract; T4 = Positive control with fitoklin; M = Mean; SD = Standard deviation

Table 3. CE and RE of plant extracts

Treatment	Blanca Junín			Pasankalla		
	AUDPC	CE (%)	RE (%)	AUDPC	CE (%)	RE (%)
T0	1,951.9			1,815.2		
T1	1,617.7	17.1	68.4	1,555.3	14.3	67.5
T2	1,682.4	13.8	55.2	1,617.5	10.9	51.4
T3	1,685.2	13.7	54.6	1,574.3	13.3	62.6
T4	1,463.5	25.0	100.0	1,430.3	21.2	100.0

Note: T0 = Negative control without extract (only water); T1 = *A. sativum* extract; T2 = *E. bogotense* extract; T3 = *C. ambrosioides* extract; T4 = Positive control with fitoklin. The control efficacy (CE) was calculated using Abbott's formula (1925), based on the AUDPC values presented in Table 1. T4 treatment was set as the maximum reference (100%) to determine the relative efficacy (RE)

reflects that even an effective systemic fungicide can achieve only limited disease suppression. This reality underscores a central tenet of modern plant pathology: exclusive reliance on chemical solutions is rarely sustainable or sufficient. The limited CE of the reference standard reinforces the need for an opportunity to integrate complementary alternatives, such as plant extracts, into integrated pest management (IPM) strategies.

Variety interaction × treatment and practical perspective

One of the most significant findings of this study was the marked and statistically consistent variety × treatment interaction, evidenced by the disease progression curves (Table 1), the efficacy metrics (Table 3), and the agronomic parameters (Table 2). This interaction is a quantifiable manifestation of how the response to a control strategy is modulated by the host's genetic makeup. The Blanca Junín variety, identified as the most susceptible, exhibited a positive response to the treatments, particularly the *A. sativum* extract, with significantly greater reductions in severity and percentage yield gains. Conversely, the Pasankalla variety, with greater tolerance, showed a more moderate response, where the increases attributable to the treatments were smaller in both absolute and relative magnitude.

A key finding in this study was the marked interaction between variety and treatment with plant extracts, which aligns with findings from several authors regarding genetic variability in downy mildew susceptibility in quinoa crops (Colque-Little et al., 2021). The Pasankalla variety, considered moderately tolerant, exhibited lower severity levels and smaller relative yield gains after the application of aqueous extracts. In contrast, Blanca Junín, which is more susceptible, showed more pronounced disease reductions and substantial yield increases, especially with the aqueous extract of *A. sativum*. This difference in response suggests that the observable efficacy of a treatment depends not only on its intrinsic antifungal activity but also on the level of susceptibility and the physiological recovery capacity of the genotype against early damage caused by *P. variabilis*. Previous studies indicated that tolerant varieties show more moderate losses even without applications (Pardo et al., 2020; Galecio-Julca et al., 2023).

Furthermore, the good performance of the aqueous garlic extract on a susceptible variety suggests that this treatment could play an important role as a management alternative for cropping systems where fungicide availability is limited or where the goal is to reduce dependence on synthetic inputs. This is particularly relevant in high-Andean regions, where family farming faces economic and logistical constraints, and downy mildew is one of the main health problems affecting quinoa cultivation. Plant extracts, when easy to prepare and economically accessible, can promote the adoption of appropriate agroecological practices that are compatible with the producer's circumstances.

Limitations

Plant extracts have inherent limitations: their chemical composition can vary depending on the origin of the plant material, storage conditions, extraction temperature, and the time elapsed between preparation and application. This variability could explain some of the dispersion observed between replicates or between evaluation dates. Therefore, it is recommended that future studies incorporate phytochemical analyses to standardize active compound concentrations and dose-response experiments to reveal optimal application levels. Another relevant line of research involves evaluating mixtures of extracts with synthetic fungicides, which could allow for reduced chemical doses without compromising efficacy, in addition to delaying the development of pathogen resistance.

It is also important to highlight that this study was conducted during a single growing season and at a single site, so the generalizability of the results should be considered with caution. Factors such as rainfall, nighttime temperature, leaf wetness, and initial inoculum pressure can significantly modify downy mildew dynamics and the efficacy of aqueous extracts. Therefore, multi-site and multi-season trials are recommended to evaluate the agronomic consistency of the treatments studied.

CONCLUSIONS

This study demonstrated that the evaluated aqueous extracts have potential for managing downy mildew caused by *P. variabilis* in quinoa cultivation. However, their efficacy varies considerably depending on the treatment and variety evaluated. The aqueous extract of *A. sativum* was the most effective, achieving significant reductions in disease severity and AUDPC, and generating yield increases, especially in the susceptible variety Blanca Junín, where its relative efficacy was comparable to that of the fungicide metalaxyl. The aqueous extracts of *E. bogotense* and *C. ambrosioides* showed intermediate effects, with moderate reductions in disease progression. The strong interaction between variety and treatment highlights the importance of considering genetic susceptibility when choosing management strategies. In tolerant varieties such as Pasankalla, the agronomic benefits of aqueous extracts were more limited. Overall, the results indicate that the aqueous extract of *A. sativum* is a viable alternative for low-input farming systems and could be integrated into controlled mildew management programs in conventional quinoa crops. However, validation over several growing seasons and under different environmental conditions is required before recommending its widespread adoption.

REFERENCES

Abbott, W. S. (1925). A method of computing the effectiveness of an insecticide. *Journal of Economic Entomology*, *18*(2), 265–267. https://doi.org/10.1093/jee/18.2.265a

Apaza Ticona, J., Alanoca Arocutipa, V., Cutipa Añamuro, G., Calderon Torres, A., Quenta Paniagua, R. A., & Apaza Chino, G. (2022). Sabiduría tradicional para la crianza de cultivo de quinua (*Chenopodium quinoa* Willd.) y uso en las comunidades aymaras (Puno-Perú). *Anales de Geografía de la Universidad Complutense*, *42*(1), 11–30. https://doi.org/10.5209/aguc.81793

Bazile, D. (2024). Perspectivas de granos andinos en Europa y en el mundo: la quinoa, desafíos y perspectivas de una conquista del mundo. *Día Nacional de los Granos Andinos* (pp. 3-p). Centro de Investigación e Innovación en Productos Derivados de Cultivos Andinos. Retrieved from https://hal.science/hal-05182285/document

Bazile, D., Bertero, D., & Nieto, C. (2015). *State of the art report of quinoa around the world in 2013*. FAO & CIRAD. Retrieved from https://openknowledge.fao.org/handle/20.500.14283/i4042e

Cenobio-Galindo, A. D. J., Hernández-Fuentes, A. D., González-Lemus, U., Zaldívar-Ortega, A. K., González-Montiel, L., Madariaga-Navarrete, A., & Hernández-Soto, I. (2024). Biofungicides based on plant extracts: On the road to organic farming. *International Journal of Molecular Sciences*, *25*(13), 6879. https://doi.org/10.3390/ijms25136879

Christensen, S. A., Pratt, D. B., Pratt, C., Nelson, P. T., Stevens, M. R., Jellen, E. N., & Maughan, P. J. (2007). Assessment of genetic diversity in the USDA and CIP-FAO international nursery collections of quinoa (*Chenopodium quinoa* Willd.) using microsatellite markers. *Plant Genetic Resources*, *5*(2), 82–95. https://doi.org/10.1017/S1479262107672293

Colque-Little, C., Abondano, M. C., Lund, O. S., Amby, D. B., Piepho, H. P., Andreasen, C., ... & Schmid, K. (2021). Genetic variation for tolerance to the downy mildew pathogen *Peronospora variabilis* in genetic resources of quinoa (*Chenopodium quinoa* Willd.). *BMC Plant Biology*, *21*(1), 41. https://doi.org/10.1186/s12870-020-02804-7

Cruces, L., Callohuari, Y., & Carrera, C. (2016). *Quinua, manejo integrado de plaga. Estrategias en el cultivo de la quinua para fortalecer el sistema agroalimentario en la zona andina*. Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO). Retrieved from http://www.fao.org/3/a-i6038s.pdf

Da Cruz Cabral, L., Fernández Pinto, V., & Patriarca, A. (2013). Application of plant derived compounds to control fungal spoilage and mycotoxin production in foods.

International Journal of Food Microbiology, *166*(1), 1–14. https://doi.org/10.1016/j.ijfoodmicro.2013.05.026

Dalal, A., Attia, Z., & Moshelion, M. (2017). To produce or to survive: How plastic is your crop stress physiology? *Frontiers in Plant Science*, *8*, 2067. https://doi.org/10.3389/fpls.2017.02067

Danielsen, S., & Ames, T. (2008). *El mildiu (Peronospora farinosa) de la quinua (Chenopodium quinoa* Willd.*) en la zona andina: Manual práctico para el estudio de la enfermedad y del patógeno*. Centro Internacional de la Papa (CIP). Retrieved from https://cipotato.org/wp-content/uploads/2014/10/AN60198.pdf

Danielsen, S., & Munk, L. (2004). Evaluation of disease assessment methods in quinoa for their ability to predict yield loss caused by downy mildew. *Crop Protection*, *23*(3), 219–228. https://doi.org/10.1016/j.cropro.2003.08.010

Danielsen, S., Bonifacio, A., & Ames, T. (2003). Diseases of quinoa (*Chenopodium quinoa* Willd.). *Food Reviews International*, *19*(1–2), 43–59. https://doi.org/10.1081/FRI-120018867

Danielsen, S., Jacobsen, S. E., & Hockenhull, J. (2002). First report of downy mildew of quinoa caused by *Peronospora farinosa* f. sp. *Chenopodii* in Denmark. *Plant Disease*, *86*(10), 1175. https://doi.org/10.1094/PDIS.2002.86.10.1175B

Estrada-Zúniga, R., Apaza-Mamani, V., Pérez-Ávila, A. A., Altamirano-Pérez, A. M., Neyra-Valdez, E., & Bobadilla, L. G. (2022). Comportamiento agronómico de 81 genotipos de quinua (*Chenopodium quinoa* Willd.) en el Perú. *Ecosistemas y recursos agropecuarios*, *9*(1), 3134. https://doi.org/10.19136/era.a9n1.3134

Fufa, B. K. (2019). Anti-bacterial and anti-fungal properties of garlic extract (*Allium sativum*): A review. *Microbiology Research Journal International*, *28*(3), 1–5. https://doi.org/10.9734/mrji/2019/v28i330133

Fukuzaki, S. (2006). Mechanisms of actions of sodium hypochlorite in cleaning and disinfection processes. *Biocontrol Science*, *11*(4), 147–157. https://doi.org/10.4265/bio.11.147

Galecio-Julca, M., Neira-Ojeda, M., Chanduvi-García, R., Peña-Castillo, R., Álvarez-Bernaola, L. A., Granda-Wong, C., ... & Morales-Pizarro, A. (2023). Efecto de la eficacia de los microorganismos nativos y la composta en tres pisos altitudinales en el cultivo de quinua (*Chenopodium quinoa*) variedad INIA 415-Pasankalla. *Terra Latinoamericana*, *41*, 1–12. https://doi.org/10.28940/terra.v41i0.1622

García, D., Ramos, A. J., Sanchis, V., & Marín, S. (2013). Equisetum arvense hydro-alcoholic extract: Phenolic composition and antifungal and antimycotoxigenic effect against *Aspergillus flavus* and *Fusarium verticillioides* in stored maize. *Journal of the Science of Food and Agriculture*, *93*(9), 2248–2253. https://doi.org/10.1002/jsfa.6033

García-Torres, S. M., Teixeira, J. A., Encina-Zelada, C. R., Silva, C. L., & Gomes, A. M. (2025). Effect of different disinfection procedures on the microbiological quality and germination efficacy of sprouted quinoa (*Chenopodium quinoa* Willd.) flour. *Foods*, *14*(18), 3196. https://doi.org/10.3390/foods14183196

Gisi, U., & Cohen, Y. (1996). Resistance to phenylamide fungicides: A case study with *Phytophthora infestans* involving mating type and race structure. *Annual Review of Phytopathology*, *34*(1), 549–572. https://doi.org/10.1146/annurev.phyto.34.1.549

Hanson, K., & Shattock, R. C. (1998). Effect of metalaxyl on formation and germination of oospores of *Phytophthora infestans*. *Plant Pathology*, *47*(2), 116–122. https://doi.org/10.1046/j.1365-3059.1998.00215.x

Hayat, S., Cheng, Z., Ahmad, H., Ali, M., Chen, X., & Wang, M. (2016). Garlic, from remedy to stimulant: Evaluation of antifungal potential reveals diversity in phytoalexin allicin content among garlic cultivars; allicin containing aqueous garlic extracts trigger antioxidants in cucumber. *Frontiers in Plant Science, 7,* 1235. https://doi.org/10.3389/fpls.2016.01235

Jaramillo, B. E., Duarte, E., & Delgado, W. (2012). Bioactividad del aceite esencial de *Chenopodium ambrosioides* colombiano. *Revista Cubana de Plantas Medicinales*, *17*(1), 54–64. Retrieved from https://www.medigraphic.com/pdfs/revcubplamed/cpm-2012/cpm121f.pdf

Kumar, R., Mishra, A. K., Dubey, N. K., & Tripathi, Y. B. (2007). Evaluation of *Chenopodium ambrosioides* oil as a potential source of antifungal, antiaflatoxigenic and antioxidant activity. *International Journal of Food Microbiology*, *115*(2), 159–164. https://doi.org/10.1016/j.ijfoodmicro.2006.10.017

Langsi, D. J., Nukenine, E. N., Fokunang, C. N., Suh, C., & Goudoungou, W. J. (2017). Potentials of essential oils of *Chenopodium ambrosioides* L. and *Cupressus sempervirens* L. against stored maize pest, *Sitophilus zeamais* Motschulsky. *Journal of Entomology and Zoology Studies*, *5*(2), 309–313. Retrieved from https://www.entomoljournal.com/archives/2017/vol5issue2/PartE/5-1-238-716.pdf

Li, S., & Zhihui, C. (2008). *Allium sativum* extract as a biopesticide affecting pepper blight. *International Journal of Vegetable Science*, *15*(1), 13–23. https://doi.org/10.1080/19315260802446377

Makia, R., Al.sammarrae, K. W., Al-Halbosiy, M. M., & Al-Mashhadani, M. H. (2022). Phytochemistry of the genus Equisetum (*Equisetum arvense*). *GSC Biological and Pharmaceutical Sciences*, *18*(02), 283–289. https://doi.org/10.30574/gscbps.2022.18.2.0059

Norman, D. W., Worman, F. D., Siebert, J. D., & Modiakgotla, E. (1995). *The farming systems approach to development and appropriate technology generation*. Rome: FAO Publication. Retrieved from https://www.fao.org/4/v5330e/v5330e00.htm

Pando, L., & Aguilar, E. (2016). Guía de cultivo de la quinua. *Organización de las Naciones Unidas para la Alimentación y la Agricultura, Universidad Nacional Agraria La Molina*, *2*, 17–18. Retrieved from https://openknowledge.fao.org/server/api/core/bitstreams/76594aca-c6a8-45e0-97db-39905cd72575/content/

Pánek, M., Ali, A., & Helmer, Š. (2022). Use of metalaxyl against some soil plant pathogens of the class peronosporomycetes-A review and two case studies. *Plant Protection Science*, *58*(2), 92–109. https://doi.org/10.17221/42/2021-PPS

Pardo, M. S., Allende Burga, R., & Romero Carrión, V. L. (2020). Estudio comparativo en rendimiento y calidad de 12 variedades de quinua orgánica en la comunidad campesina de San Antonio de Manallasac, Ayacucho. *Revista Campus de la Facultad de Ingeniería y Arquitectura de la Universidad de San Martin de Porres*, *29*, 57–66. https://doi.org/10.24265/campus.2020.v25n29.04

Pathan, S., & Siddiqui, R. A. (2022). Nutritional composition and bioactive components in quinoa (*Chenopodium quinoa* Willd.) greens: A review. *Nutrients*, *14*(3), 558. https://doi.org/10.3390/nu14030558

Pérez, Á. A. (2005). *Manejo del cultivo de quinua en la sierra central*. *Serie Manual; Nº 1-05*. Instituto Nacional de Investigación y Extensión Agraria-INIA. Retrieved from https://repositorio.inia.gob.pe/server/api/core/bitstreams/0064586d-101a-4568-8d68-65093c27eff9/content

Roy, C. K., Akter, N., Sarkar, M. K., Pk, M. U., Begum, N., Zenat, E. A., & Jahan, M. A. (2019). Control of early blight of tomato caused by *Alternaria solani* and screening of tomato varieties against the pathogen. *The Open Microbiology Journal*, *13*(1), 41–50. https://doi.org/10.2174/1874285801913010041

Rubén, D., Burin, D., Pereyra, E., & Heras, A. I. (2015). *Quinua, regalo ancestral: Historia, contexto, tecnología, políticas*. Fundación Nueva Gestión. Retrieved from https://n2t.net/ark:/13683/poQx/DzD

Ruiz, K. B., Biondi, S., Oses, R., Acuña-Rodríguez, I. S., Antognoni, F., Martinez-Mosqueira, E. A., ... & Molina-Montenegro, M. A. (2014). Quinoa biodiversity and sustainability for food security under climate change. A review. *Agronomy for Sustainable Development*, *34*(2), 349–359. https://doi.org/10.1007/s13593-013-0195-0

Sandhu, N. S., Kaur, S. A., & Chopra, D. I. (2010). *Equisetum arvense*: Pharmacology and phytochemistry-a review. *Asian Journal of Pharmaceutical and Clinical Research*, *3*(3), 146–150. Retrieved from https://web.archive.org/web/20180410062011id_/http://www.ajpcr.com/Vol3Issue3/3.pdf

Sanjai, C., Gaonkar, S. L., & Hakkimane, S. S. (2024). Harnessing nature's toolbox: Naturally derived bioactive compounds in nanotechnology enhanced formulations. *ACS Omega*, *9*(43), 43302–43318. https://doi.org/10.1021/acsomega.4c07756

Sarfraz, M., Nasim, M. J., Jacob, C., & Gruhlke, M. C. (2020). Efficacy of allicin against plant pathogenic fungi and unveiling the underlying mode of action employing yeast based chemogenetic profiling approach. *Applied Sciences*, *10*(7), 2563. https://doi.org/10.3390/app10072563

Shah, H. (2014). Antibacterial and antifungal activities of the crude extracts from the stem of *Chenopodium ambrosioides* Linn., an indiginous medicinal plant. *African Journal of Pharmacy and Pharmacology*, *8*(8), 231–234. https://doi.org/10.5897/AJPP2014.4010

Simko, I., & Piepho, H. P. (2012). The area under the disease progress stairs: Calculation, advantage, and application. *Phytopathology*, *102*(4), 381–389. https://doi.org/10.1094/PHYTO-07-11-0216

Singh, J. (2008). Maceration, percolation and infusion techniques for the extraction of medicinal and aromatic plants. *Extraction technologies for medicinal and aromatic plants*, *67*, 32–35. United Nations Industrial Development Organization, UNIDO. Retrieved from https://www.unido.org/sites/default/files/2009-10/Extraction_technologies_for_medicinal_and_aromatic_plants_0.pdf

Slusarenko, A. J., Patel, A., & Portz, D. (2008). Control of plant diseases by natural products: Allicin from garlic as a case study. *Sustainable disease management in a European context*. Springer. https://doi.org/10.1007/978-1-4020-8780-6_10

Sud, U. C., Ahmad, T., Gupta, V. K., Chandra, H., Sahoo, P. M., Aditya, K., ... & Biswas, A. (2017). *Methodology for estimation of crop area and crop yield under mixed and continuous cropping*. ICAR-Indian Agricultural Statistics Research Institute: New Delhi, India. Retrieved from https://openknowledge.fao.org/server/api/core/bitstreams/ca36b8c1-99b6-4cad-ad88-ff018647a474/content

Sureshkumar, J., Jenipher, C., Sriramavaratharajan, V., Gurav, S. S., Gandhi, G. R., Ravichandran, K., & Ayyanar, M. (2023). Genus *Equisetum* L: Taxonomy, toxicology, phytochemistry and pharmacology. *Journal of Ethnopharmacology*, *314*, 116630. https://doi.org/10.1016/j.jep.2023.116630

Testen, A. L., del Mar Jiménez-Gasco, M., Ochoa, J. B., & Backman, P. A. (2014). Molecular detection of *Peronospora variabilis* in quinoa seed and phylogeny of the quinoa downy mildew pathogen in South America and the United States. *Phytopathology*, *104*(4), 379–386. https://doi.org/10.1094/PHYTO-07-13-0198-R

Trebbi, G., Negri, L., Bosi, S., Dinelli, G., Cozzo, R., & Marotti, I. (2021). Evaluation of *Equisetum arvense* (horsetail macerate) as a copper substitute for pathogen management in field-grown organic tomato and durum wheat cultivations. *Agriculture*, *11*(1), 5. https://doi.org/10.3390/agriculture11010005

Vega-Gálvez, A., Miranda, M., Vergara, J., Uribe, E., Puente, L., & Martínez, E. A. (2010). Nutrition facts and functional potential of quinoa (*Chenopodium quinoa* Willd.), an ancient Andean grain: A review. *Journal of the Science of Food and Agriculture*, *90*(15), 2541–2547. https://doi.org/10.1002/jsfa.4158

Wang, M., Gao, L., Dong, S., Sun, Y., Shen, Q., & Guo, S. (2017). Role of silicon on plant–pathogen interactions. *Frontiers in Plant Science*, *8*, 701. https://doi.org/10.3389/fpls.2017.00701

Wei, W., Chen, P., Khan, B., Tian, K., Feng, Y., Lv, B., ... & Liu, G. (2024). Evaluation of equisetin as an anti-microbial and herbicidal agent from endophytic fungus *Fusarium* sp. JDJR1. *Agronomy*, *14*(1), 31. https://doi.org/10.3390/agronomy14010031