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Peracetic acid for powdery mildew (*Erysiphe vaccinii*) management in blueberry (*Vaccinium corymbosum*) under commercial condition in Peru

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ABSTRACT

Background/Objective. Blueberry powdery mildew, associated with *Erysiphe vaccinii*, is a foliar disease that may cause defoliation and affect crop performance. In Peru, information on the foliar use of peracetic acid for its field management is limited. The objective of this study was to evaluate the effect of foliar applications of 15% peracetic acid on powdery mildew incidence in blueberry under field conditions in Ica, Peru.

Experimental development. The trial was conducted in a commercial field of blueberry cv. Biloxi in Ica, Peru, using a randomized complete block design with five treatments: an untreated control and 15% peracetic acid at 2, 4, 6, and 8 mL L^{-1}, with four replicates. Treatments were applied as foliar sprays twice, seven days apart, at a spray volume of 600 L ha^{-1}. The response variable was the incidence of leaves with powdery mildew symptoms (under natural infection), assessed on seven dates from the first application onward. The presence of phytotoxicity symptoms was also visually recorded.

Results. Before the first application, no differences were detected among treatments. After the first application, peracetic acid reduced powdery mildew incidence compared with the control, with initial efficacy of up to 67.7%. After the second application, the 4, 6, and 8 mL L^{-1} doses showed the best response, with maximum efficacies of 69.3, 78.0, and 79.7%, respectively. The 2 mL L^{-1} dose showed a lower effect. No visible phytotoxicity symptoms were observed at any of the evaluated doses.

Conclusion. Under the conditions of this trial, 15% peracetic acid reduced foliar powdery mildew incidence in blueberry, with the best response at 4, 6, and 8 mL L^{-1} (69.3, 78.0, and 79.7%). These results indicate a favorable effect of the product under field conditions, although further evaluation in additional locations or growing seasons is needed for validation.

Keywords: cv. Biloxi, Foliar incidence, Phytotoxicity, Agricultural oxidant, Foliar spray

INTRODUCTION

The blueberry (*Vaccinium corymbosum*) has been consolidated as one of the most important fruit crops for export in Peru, with a steady growth in production and exports in recent years (MIDAGRI, 2024; USDA-FAS, 2025). For the 2025/26 season, the USDA-FAS (2025) projected Peruvian production of 355 000 t and exports of 335 000 t, which reflects the current scale of the crop and the need to maintain its health in production intensive systems (MIDAGRI, 2024; USDA-FAS, 2025).

Among the phytosanitary problems of the crop, powdery mildew has gained interest for its ability to impact leaves and force repeated control interventions (Bradshaw *et al*., 2025). In particular, *Erysiphe vaccinii* has recently been described as an emerging species of powdery mildew that is impacting the blueberry industry and quickly expanding outside of North America towards other production areas, including China, Morocco, Mexico and the United States (Bradshaw *et al*., 2025). In Peru, although the available indexed literature is still limited, no field evaluations have been published for the management of powdery mildew in Piura, Peru; which confirms the local relevance of the problem and the need to generate experimental evidence under Peruvian production conditions (Alvarez Romero and Mattos Calderón, 2022).

Powdery mildew management in perennial crops is often based on specific-action fungicides; however, the powdery mildew-causing fungi have well-documented histories of reduced sensitivity, resistance and failure to control groups such as sterol demethylation inhibitors (DMI), QoI inhibitors and SDHI inhibitors (Vielba-Fernández *et al*., 2020). Consistent with this, the Fungicide Resistance Action Committee (FRAC) indicates that resistance management depends on the intrinsic risk of the fungicide, on the risk of the pathogen and the agricultural context, and it recommends avoiding repeated applications of the same form of in high-risk pathogens; for situations involving spraying, it recommends alternation or mixtures with effective fungicides without cross-resistance (Fungicide Resistance Action Committee [FRAC], 2024a, 2024b). Hence, it is worth evaluating complementary tools that can be integrated into the management of powdery mildew without depending exclusively on conventional fungicides (FRAC, 2024a, 2024b; Vielba-Fernández *et al*., 2020).

Within those tools, the peroxygen compounds, among which is peracetic acid, have been used in agriculture and horticulture for around 30 years as disinfectants against plant pathogens (Copes and Ojiambo, 2023). In a systematic revision and a metanalysis of 95 studies, Copes and Ojiambo (2023) reported a high worldwide effect of these compounds against phytopathogenic fungi, although they also showed that the magnitude of the response varies according to the active ingredient and the material treated, and that the efficacy tends to be less in plant and fruit tissues than in seeds. Consequently, its effect as a foliar application on powdery mildew on blueberry must not be extrapolated from other crops or systems and requires specific validation in the field (Copes and Ojiambo, 2023). Based on was that two foliar applications of a 15% peracetic acid formulation would reduce the incidence of powdery mildew without causing visible phytotoxicity. Due to this, the aim of this study was to evaluate the effect of different doses of 15% peracetic acid on the foliar incidence of powdery mildew in blueberry cv. Biloxi under field conditions in Ica, Peru.

EXPERIMENTAL DEVELOPMENT

Study site. The trial was held during the 2024 season un a commercial blueberry (*Vaccinium corymbosum*) cv. Biloxi field, located in the Villacurí archaeological area, in the Salas-Guadalupe district, in the province and department of Ica, Peru. The crop consisted of a mature plantation in commercial production, established under an intensive system, with an approximate density of 7 000 plants ha^{-1}. During the study period, maximum temperatures ranged from 25.4 to 28.0 °C, minimum temperatures ranged from 6.2 to 10.3 °C, relative maximum humidity, from 73 y 79%, and no rainfalls were recorded.

Phytopathological diagnosis. The disease was diagnosed in the field based on the presence of chlorotic to reddish areas, leaf curling and white powdery mycelial growth on the surface of the leaf—symptoms and signs consistent with blueberry powdery mildew. In advanced stages, defoliation and yellow to black sex structures may appear on the affected tissue. In line with these descriptions and with recent literature on blueberry powdery mildew, it was associated with *Erysiphe vaccinii* (Alvarez Romero and Mattos Calderón, 2022; Bradshaw *et al*., 2025).

Experimental design and treatments. A liquid peracetic acid formulation at 15%, manufactured in Peru, was evaluated under a complete randomized block design with five treatments and four repetitions: a control without applying and peracetic acid at 15% at 2.0, 4.0, 6.0 and 8.0 mL L^{-1}. Each experimental unit was composed of two adjacent 3.5 m-long rows, with an approximate useful area of 7.0 m^2 per plot. A total of 20 experimental units were established. The treatments were assigned at random within each block and the rows of the edges were avoided as evaluation areas to reduce edge effects or spray drift.

Application of the treatments. The applications were carried out using a motor-powered backpack sprayer equipped with a cone nozzle, adjusted to spray a volume equivalent to 600 L ha^{-1}, with an estimated discharge between 1.35 and 1.52 L min^{-1}, ensuring an even canopy coverage. The solutions were prepared by initially adding half of the volume of water to the motor-powered backpack; later, the corresponding dose of peracetic acid at 15% is added and completed with the remaining volume of water, shaking constantly before and during application. Two foliar applications were carried out: the first was on July 31, 2024, and the second one, on August 7, 2024, when the crop displayed initial powdery mildew infections. During the trial, no other fungicides were applied on the experimental plots.

Evaluation of the disease. The evolution of the disease was natural, with previous records of its presence in the crop. The response variable was the foliar incidence of powdery mildew, defined as the percentage of leaves with visible signs and/or symptoms of infection. Evaluations were performed visually and in a non-destructive way. In each experimental unit, 100 leaves were chosen at random from the middle stratum and classified as “with powdery mildew” or “healthy”, and the percentage of leaves affected in every treatment and date were calculated. A total of seven evaluations were performed: one prior to the first application and six afterwards, on days 3, 5 and 7 days after the first application and on days 3, 5 and 7 days after the second application.

Phytotoxicity and experimental management. On the same days as the evaluations, the presence or absence of symptoms of phytotoxicity on leaves and fruits, such as chlorosis, necrosis, malformations or burning were qualitatively recorded. During the whole experimental period, an even agronomic management was maintained between plots.

Statistical analysis. The data on the incidence of powdery mildew, expressed as percentages of affected leaves, were transformed using the square root of (x + 1) before the analysis to stabilize the variance. Subsequently, an analysis of variance (ANOVA) was carried out for a complete randomized block design in order to evaluate the effect of the treatments on every evaluation day. When significant differences were found ($p < 0.05$), the means were compared using Duncan's test ($\alpha = 0.05$). The percentage efficacy of each treatment relative to the control was estimated using Abbott's formula: Efficacy (%) = $[1 - (T/C)] \times 100$, where T represents the incidence observed in the treatment and C is the incidence observed in the control on the same date of evaluation. All analyses were carried out using the Statgraphics Centurion XIX statistical package.

The initial incidence of powdery mildew, recorded before the first application, was low and statistically similar between treatments, with values ranging between 6.0 and 8.8% in the treated plots and 6.5% in the absolute control (Table 1). This homogenous initial condition makes it possible to attribute subsequent changes to the effect of the treatments. Three days after the first application, the doses of 4, 6 and 8 mL L^{-1} reduced the incidence to 3.0, 2.8 and 2.5%, respectively, against 7.8% in the control, whereas the dose of 2.0 mL L^{-1} presented an immediate response (3.5%) (Table 1). On days five and six after the first application, a progressive separation was maintained between treatments, with lower disease levels in the doses greater than or equal to 4.0 mL L^{-1}, suggesting a response dependent on the dose from the first intervention (Table 1) (Iglesias-Osores and Figueroa-Palomino, 2026). This pattern coincides with the superficial biology of the powdery mildew and with the behavior expected from peroxygen compounds by contact, whose efficacy depends on the concentration applied, time of exposure and coverage achieved on the treated tissue (Glawe, 2008; Carrasco and Urrestarazu, 2010; Copes and Ojiambo, 2023).

After the second application, the differences between treatment were more noticeable. The absolute control reached incidences of 14.8, 17.0 and 18.8% on days 3, 5 and 7 after the second application, respectively, remaining in the group with the highest incidence in all cases (Table 1). By contrast, the 2.0 mL L^{-1} dose was consistently found at an intermediate stage, with values between 3.8 and 7.3%, whereas the doses of 4, 6 and 8 mL L^{-1} presented the lowest incidences, between 3.0 y 5.8%, grouped in the lowest statistical level (Table 1). Jointly, these results indicate that, under the conditions of the trial, doses greater than or equal to 4.0 mL L^{-1} were the most consistent in reducing the foliar incidence of the powdery mildew. The greatest differentiation observed after the second application is with studies in which the effect of the control with formulations based on peracetic acid increased when increasing the dose or with repeated applications, as described for powdery mildew in okra (*Abelmoschus esculentus*) and sunflower (*Helianthus annuus*), and in preharvest treatments against fungal rots in strawberry (*Fragaria* × *ananassa*) (Galal, 2017; Yang *et al*., 2022).

Table 1. Foliar incidence of powdery mildew in blueberry treated with 15% peracetic acid at seven evaluation dates.

Treatment	B. 1st A	3 DAA 1st A	5 DAA 1st A	7 DAA 1st A	3 DAA 2nd A	5 DAA 2nd A	7 DAA 2nd A
Untreated control	6.5 a	7.8 a	9.8 a	11.5 a	14.8 a	17.0 a	18.8 a
2 mL L^{-1}	8.3 a	3.5 ab	4.5 ab	5.8 ab	3.8 b	5.0 b	7.3 b
4 mL L^{-1}	8.8 a	3.0 b	4.0 bc	4.5 bc	3.5 c	4.5 c	5.8 c
6 mL L^{-1}	6.0 a	2.8 b	3.8 bc	4.8 c	3.3 c	3.8 c	5.3 c
8 mL L^{-1}	7.8 a	2.5 b	3.5 c	4.0 c	3.0 c	4.8 c	5.0 c

Means followed by the same letter within the same column indicate no significant differences among treatments (Duncan's test), $p < 0.05$).

The behavior observed in Ica can be contrasted with precedents available for powdery mildew in blueberry in Peru. Alvarez Romero and Mattos Calderón (2022), in a study performed in Piura, Peru; on organic blueberry, reported efficacies of 61.85% with potassium bicarbonate and 42.81% with sulfur on the incidence, whereas for severity, the best treatments reached 73.96, 56.7 and 54.82%. In this study, peracetic acid at 15% reached maximum efficacies between 69.3 and 79.7% on incidence after the second application (Table 2), values of the same order or superior to several alternative treatments previously evaluated in Peru. However, it is worth noting that results can vary depending on the location, environment, application scheme and response variable, since severity was also evaluated in Piura (Alvarez Romero and Mattos Calderón, 2022). A similar case appears in powdery mildew in other fruits: in organic apple trees, the best response with bicarbonates were observed when they were combined with wettable sulfur, whereas in grapevine, the efficacy of alternative materials against powdery mildew was highly variable between seasons and cultivars (Holb and Kunz, 2016; Savocchia *et al*., 2011).

Table 2. Control efficacy against powdery mildew in blueberry treated with 15% peracetic acid, estimated using Abbott's formula.

Treatment	B. 1st A	3 DAA 1st A	5 DAA 1st A	7 DAA 1st A	3 DAA 2nd A	5 DAA 2nd A
2 mL L^{-1}	35.5	33.3	30.4	57.6	51.5	44.0
4 mL L^{-1}	61.3	59.0	60.9	76.3	73.5	69.3
6 mL L^{-1}	64.5	61.5	58.7	78.0	77.9	72.0
8 mL L^{-1}	67.7	64.1	65.2	79.7	72.1	73.3

[z] Efficacy calculated relative to the untreated control using Abbott's formula.

The percentage of control calculated using Abbott's formula showed that the efficacy of peracetic acid at 15% increase with the dose and the second application. After the first application, the control values fluctuated between 35.5 and 67.7% after three days, with the highest percentages in 6 and 8 mL L^{-1} (Table 2). Seven days after the first application, efficiencies remained between 30.4 and 65.2%, once again with better responses in the doses of 4 to 8 mL L^{-1} (Table 2). After the second application, the control increased in all treatment and reached values between 57.6 and 79.7% after three days, whereas on days 5 and 7, the 4, 6 y 8 mL L^{-1} doses kept control percentages of over 69.3%, respectively (Table 2). The 2 mL L^{-1} dose presented more moderate efficacies, between 44.0 and 57.6 % (Table 2). This pattern coincides with the systematic revision and metanalysis by Copes and Ojiambo (2023), who found a high global effect of the peroxygen compounds against phytopathogenic fungi, but also a high heterogeneity between studies, associated to the active ingredient, the material treated, the dose and time of contact. This variability has also been discussed by Carrasco and Urrestarazu (2010) for protected horticultural systems and by Schöneberg *et al*. (2024) on berries (*Rubus* spp.), where a PAA-H_2O_2 sanitizer showed field effects dependent on the context and the pressure of the system.

The favorable response observed in blueberries does not imply that the peroxide-and peroxyacetic acid-based compounds are evenly efficient in all pathosystems. In tomato (*Solanum lycopersicum*), Egel *et al*. (2019) reported that a program alternated with OxiDate 2.0 did not consistently reduce the disease levels against the control in field and greenhouse trials, which shows that the performance of this type of products depends on the host, the pathogen and the application scheme. Consistently, in blueberry, it has been reported that PAA-H_2O_2 formulations can occasionally reduce the abundance of fungi under low pressure, but they do not necessarily provide robust and even access across all field scenarios (Schöneberg *et al*., 2024). On the other hand, PMRA (2018) pointed out that formulations with hydrogen peroxide and peroxyacetic acid can be an alternative that reduces or delays the need for conventional fungicides under low disease pressure, although its value is presented as partial elimination and not as a universal replacement of residual fungicides. Overall, these findings support a cautious interpretation of the results of the present study, in which 15% peracetic acid displayed biological activity in the field against the powdery mildew in blueberry (Tables 1 and 2).

The relevance of these findings increases when considering that *Erysiphe vaccinii* has been recently acknowledged as an emerging species that is affecting the blueberry industry and expanding out of North America towards other production regions (Bradshaw *et al*., 2025). At the same time, powdery mildew constitutes a group of pathogens with a broad adaptive ability and with a background of sensitivity reduction, resistance and control flaws against specific action fungicides, including DMI, QoI and SDHI (Glawe, 2008; Vielba-Fernández *et al*., 2020; Kunova *et al*., 2021). Therefore, the interest in peracetic acid in this study does not lie in presenting it as a direct substitute of conventional fungicides, but as a complementary tool that could contribute to the diversification of powdery mildew management in blueberry, particularly in programs which attempt to reduce the exclusive dependence of specific site molecules (FRAC, 2024; Vielba-Fernández *et al*., 2020; Kunova *et al*., 2021).

The interpretation of the results must consider that the present study was carried out in only one location and in one season, with an evaluation of foliar incidence, but without measurements for severity, defoliation, performance or comparisons with fungicides of commercial use. Consequently, the results support the potential of peracetic acid at 15% as a complementary tool in the management of the powdery mildew in blueberry, but they require additional validation in more environments and conditions of use.

On the other hand, during the evaluation, no visible symptoms of phytotoxicity were observed in the leaves nor the fruits of any of the treatments, including the highest dose evaluated. The absence of chlorosis, necrosis, malformation of burning in leaves suggests visual tolerance of the crop to the product under the trial conditions; however, this observation must be limited to visible damage, since no physiological or productive variables were quantified. This is important because the response of plant tissued to oxidants can vary with concentration, frequency and the phenological state, and damage thresholds have been documented in other crops exposed to hydrogen peroxide (Eicher-Sodo *et al*., 2019; Lau and Mattson, 2021).

CONCLUSIONS

Under the conditions of this field trial, 15% peracetic acid reduced the foliar incidence of powdery mildew in blueberry regarding the absolute control, with a more consistent response in the 4, 6 and 8 mL L^{-1} doses, which reached maximum efficiencies of 69.3, 78.0 y 79.7%, respectively, after the second application. The 2.0 mL L^{-1} dose displayed a lower and less stable effect. In addition, no visible signs of phytotoxicity were observed in any of the doses evaluated. These results indicate that the 15% peracetic acid has potential as a complementary tool for the management of powdery mildew under field conditions; however, its validation requires additional studies in more locations, seasons and management conditions.

Limitations. The study presented some limitations that must be considered when interpreting its results. Among them are the short evaluation period, which does not allow the efficiency of 15% peracetic acid to be extrapolated to the entire phenological cycle of blueberry; the trial being held in a single location with specific environmental conditions, which limits the generalization to other production areas; and the use of a limited range of doses and a single application method, without analyzing variations in volume or frequency. Likewise, the qualitative and short-term evaluation of non-target effects did not enable a detailed assessment of impacts on beneficial fauna or associated microbiota. Finally, the absence of conventional fungicide as a reference prevented a direct comparison of the performance of peracetic acid with the commercial alternatives of common use.

Conflict of interest. One of the authors was affiliated with Clenvi at the time of the study.

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Contribution of the authors. Sebastian Iglesias-Osores: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Luis A. Alvarez:** Methodology, Validation, Formal analysis, Supervision, Writing – review & editing.

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