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Scientific Article

Potential of bioproducts for the management of grapevine downy mildew

Potencial de bioprodutos no manejo do míldio da videira

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ABSTRACT - This study evaluated bioproducts for managing *Plasmopara viticola* in response to the demand for sustainable disease control. *In vitro* experiments assessed the effects of direct contact between sporangia and Timorex Gold® (*Melaleuca alternifolia*) or Twixx-A® (*Bacillus amyloliquefaciens*) at 1, 2, and 3 mL L^{1} by counting empty sporangia after 6 and 18 h of incubation. Twixx-A® compatibility with fungicides containing copper hydroxide, mancozeb, metalaxyl-M + mancozeb, benalaxil + mancozeb, dimethomorph, or *M. alternifolia* oil was evaluated at 50, 100, and 150% of the recommended rates. An in vivo experiment in a commercial vineyard evaluated foliar applications of Timorex Gold® and Twixx-A® at 2 and 3 mL L^{-1}. The area was divided into four blocks, with three plants evaluated per experimental unit; disease incidence and severity were assessed every four days. *In vitro*, all three Timorex Gold® concentrations and Twixx-A® at 1 mL L^{-1} reduced the number of empty sporangia after 18 h by more than 69%. Twixx-A® was compatible with fungicides containing dimethomorph, tea tree oil, and copper hydroxide. In the field trial, no statistically significant differences were detected among treatments (F-test, p>0.05). The products showed potential to reduce zoospore release; further studies should evaluate applications at other stages of crop phenology and disease development.

Keywords: *Bacillus*. Biological control. *Melaleuca alternifolia*. *Plasmopara viticola*. *Vitis vinifera*.

RESUMO - Este estudo avaliou bioprodutos para o manejo de *Plasmopara viticola*, em resposta à demanda por alternativas sustentáveis de controle de doenças. Em experimentos in vitro, foram avaliados os efeitos do contato direto de esporângios com Timorex Gold® (*Melaleuca alternifolia*) ou Twixx-A® (*Bacillus amyloliquefaciens*), nas concentrações de 1, 2 e 3 mL L^{-1}, mediante contagem de esporângios vazios após 6 e 18 h de incubação. A compatibilidade de Twixx-A® com fungicidas contendo hidróxido de cobre, mancozebe, metalaxil-M + mancozebe, benalaxil + mancozebe, dimetomorfe ou óleo de *M. alternifolia* foi avaliada a 50, 100 e 150% das doses recomendadas. Um experimento in vivo, conduzido em vinhedo comercial, avaliou aplicações foliares de Timorex Gold® e Twixx-A® nas concentrações de 2 e 3 mL L^{-1}. A área foi dividida em quatro blocos, com avaliação de três plantas por unidade experimental; a incidência e a severidade da doença foram avaliadas a cada quatro dias. In vitro, as três concentrações de Timorex Gold® e Twixx-A® a 1 mL L^{-1} reduziram o número de esporângios vazios após 18 h em mais de 69%. Twixx-A® foi compatível com fungicidas contendo dimetomorfe, óleo de melaleuca e hidróxido de cobre. No experimento de campo, não foram detectadas diferenças estatisticamente significativas entre os tratamentos (teste F, p>0,05). Os produtos apresentaram potencial para reduzir a liberação de zoósporos; estudos adicionais devem avaliar aplicações em outros estádios fenológicos da cultura e estágios de desenvolvimento da doença.

Palavras-chave: *Bacillus*. Controle biológico. *Melaleuca alternifolia*. *Plasmopara viticola*. *Vitis vinifera*.

Conflict of interest: The authors declare no conflict of interest related to the publication of this manuscript.

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INTRODUCTION

Brazil's diverse soil and climate conditions support several forms of viticulture, including traditional viticulture in the temperate southern regions, tropical viticulture in hot and semiarid areas, such as the irrigated fruit-growing region of the Sub-Middle São Francisco Valley, and winter viticulture in high-altitude areas of the Southeast and Northeast, made possible by double pruning (PEREIRA et al., 2020).

According to the International Organisation of Vine and Wine (OIV, 2023), the Brazilian grape cultivation area was 81,485 ha in 2023. Despite its importance, grape production faces complex phytosanitary challenges, particularly fungal diseases. Among these, grapevine downy mildew, caused by the oomycete *Plasmopara viticola* (*P. viticola*, Berk. & M. A. Curtis; Berl. & De Toni), is considered the most important grapevine disease in Brazil because it affects all green parts of the plant, compromising yield and quality in the current harvest and subsequent production cycles (BENDER et al., 2024).

Although summer pruning and the use of plastic coverings contribute to disease management, chemical control remains the main strategy and is often recommended preventively (BARBOSA et al., 2021). Despite the essential role of fungicides throughout agricultural history, their indiscriminate use can promote the selection of resistant pathogen populations (GHINI; KIMATI, 2000), the accumulation of residues in soil and water, and risks to human health. These

concerns are compounded by increasing regulatory restrictions and market demands for products with a lower environmental impact (BRENT; HOLLOMON, 2007).

According to Agrofit, the Phytosanitary Pesticides Information System maintained by Brazil's Ministry of Agriculture and Livestock, 188 synthetic products containing approximately 27 distinct active ingredients are registered for the control of grapevine downy mildew, but only one registered product is of biological origin (BRASIL, 2026).

Biological control agents play an important role because they employ different mechanisms against pathogens, including mycoparasitism, the production of antimicrobial metabolites, and competition for nutrients and space (EL-SHARKAWY; ABO-EL-WAFA; IBRAHIM, 2018).

Oil extracted from *Melaleuca alternifolia* Cheel (tea tree), for example, is rich in terpenes (p-cymene, terpinen -4-ol, terpinolene, 1,8-cineole, α-pinene, α-terpinene, and γ-terpinene), sesquiterpenes, and their corresponding alcohols (including the monoterpene alcohol terpineol), and has bactericidal and antiseptic properties. Terpinen-4-ol, its principal active compound, may account for approximately 30% of the oil's composition (CARSON; HAMMER; RILEY, 2006). According to Cox et al. (2001), the antimicrobial activity of tea tree oil against fungal pathogens is associated with its ability to inhibit cellular respiration and disrupt membrane permeability barriers.

By investigating the effectiveness of bioproducts for managing grapevine downy mildew, this study aligns with the United Nations Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger and Sustainable Agriculture), which seeks to eradicate hunger, achieve food security, and promote sustainable agriculture (IPEA, 2024).

Given the growing demand for sustainable agricultural practices and the need to reduce or even replace synthetic inputs conventionally used in grape production, this study aimed to evaluate the potential of bioproducts to control grapevine downy mildew on the Borborema Plateau, a high-altitude region where grape and wine production has gained recognition through internationally award-winning wines.

MATERIALS AND METHODS

Two *in vitro* experiments were conducted to assess the compatibility of the commercial biological product Twixx-A® (473.5 g L^{-1} of *Bacillus amyloliquefaciens* strain CPQBA 040-11DRM 01 + 473.5 g L^{-1} of *B. amyloliquefaciens* strain CPQBA 040-11DRM 04) with synthetic chemical fungicides used in grape production and the effects of Twixx-A® and Timorex Gold® (222.5 g L^{-1} of *Melaleuca alternifolia*) on the germination of *P. viticola* sporangia.

The *in vivo* experiment was conducted from March to May 2025 in a 0.8-ha commercial vineyard planted with 1.5-year-old 'Sauvignon Blanc' grapevines. The vineyard is owned by Vinícola Moura and is located in Camocim de São Félix, Pernambuco, 121 km from the state capital, Recife. The vines were trained on a vertical trellis system, spaced 3 × 1 m apart, irrigated daily, and fertilized according to crop requirements.

Assessment of Twixx-A® Compatibility with Fungicides

The experiment was conducted at the Plant Pathology Laboratory of the Universidade Federal do Agreste de Pernambuco (UFAPE), Garanhuns, Pernambuco, Brazil.

The effects of Manzate 800®, Galben®-M, Ridomil Gold MZ®, Garra 450® WP, Forum®, and Timorex Gold® at 50, 100, and 150% of the manufacturers' recommended rates (Table 1) on the growth of *Bacillus amyloliquefaciens*, the active component of the commercial product Twixx-A®, were evaluated using the method described by Silva et al. (2006), with a modification to the paper disk diameter. Petri dishes (9 cm in diameter) containing 20 mL of solid nutrient agar medium were inoculated with 100 µL of a suspension (1.2×10^{-6} CFU mL^{-1}) prepared by diluting commercial Twixx-A®. The suspension was spread across the medium surface with a Drigalski spatula. Filter-paper disks (0.7 cm in diameter) were then moistened with 13 µL of fungicide spray solution at each of the three concentrations and placed on the surface of the medium containing the bacterial suspension. Two disks were placed in each dish, parallel to one another and 1 cm from the edge. Each treatment comprised five replicates (dishes), and the control consisted of disks moistened with sterile distilled water.

Compatibility was assessed after 48 h of incubation in a biochemical oxygen demand (BOD) incubator at 28 ± 2 °C, based on the presence or absence of an inhibition zone around the disks. A product was classified as compatible when no inhibition zone formed around the paper disk and as incompatible when an inhibition zone was present.

Table 1. Fungicides (active ingredients) and corresponding concentrations used in the compatibility test.

Fungicides	Active ingredient (concentration)	Tested rates		
		50% rate (g a.i. L^{-1})	100% rate (g a.i. L^{-1})	150% rate (g a.i. L^{-1})
Galben®-M	BNL 8% + MCZ 65%	0.1 BNL + 0.8 MCZ	0.2 BNL + 1.6 MCZ	0.3 BNL + 2.4 MCZ
Ridomil Gold MZ®	MTL 4% + MCZ 64%	0.05 MTL + 0.80 MCZ	0.1 MTL + 1.6 MCZ	0.15 MTL + 2.4 MCZ
Manzate 800®	MCZ 80%	1.4	2.8	4.2
Forum®	DMF 50%	0.28125	0.5625	0.844
Garra 450® WP	HCu 69.1%	0.864	1.73	2.595
Timorex Gold®	*M. alternifolia* 22.25%	0.223	0.445	0.668

Active ingredients: BNL = benalaxil; MCZ = mancozeb; MTL = metalaxyl-M; DMF = dimethomorph; HCu = copper hydroxide; *M. alternifolia* = *Melaleuca alternifolia*. g a.i. L^{-1} = grams of active ingredient per liter.

Effects of Twixx-A® and Timorex Gold® on *Plasmopara viticola* Sporangial Germination

A modified version of the method described by Michel and Cavalcanti (2020) was used to evaluate the effects of *M. alternifolia* extract (Timorex Gold®) and *Bacillus amyloliquefaciens* (Twixx-A®) on *P. viticola* germination. A 40-µL aliquot of sporangial suspension (2×10^5 sporangia mL^{-1}) was mixed with 40 µL of each product solution at 2, 4, or 6 mL L^{-1} to obtain final product concentrations of 1, 2, and 3 mL L^{-1} and a sporangial concentration of 1×10^5 sporangia mL^{-1}. For the negative control (Ctrl−), sporangia were exposed to sterile distilled water. For the positive control, the fungicide Garra 450® WP (copper hydroxide, 691 g kg^{-1}) was used at the label-recommended rate (2.5 g L^{-1}).

The solutions were dispensed into multiwell plates and incubated in a BOD incubator at 25 °C in the dark. Assessments were conducted after 6 and 18 h of incubation by counting all sporangia in quadrant A of a Neubauer hemocytometer under a light microscope at 40× magnification (LABOMED Lx 300). Full sporangia (containing zoospores) were distinguished from empty sporangia (without zoospores).

Field Trial: *In Vivo* Control of Downy Mildew

The field trial was conducted at the end of the first production cycle using a randomized complete block design with four replicates (blocks). Each plot comprised five plants, and six treatments were evaluated: foliar applications of Twixx-A® or Timorex Gold® at 2 or 3 mL L^{-1}; alternating applications of Moximate and Cabrio Top (positive control, Ctrl+); and an untreated negative control (Ctrl−). Only the three central plants in each plot were used for assessments, while the outer plants served as borders.

Treatments were applied with a backpack sprayer until runoff, beginning after harvest, when the vines were already showing initial symptoms of naturally occurring downy mildew. Downy mildew incidence and severity were assessed every four days. In total, five applications were made at seven -day intervals, and nine assessments were performed.

On each plant, nine leaves at basal, middle, and apical positions were marked across three shoots. Downy mildew severity was assessed using the diagrammatic scale proposed by Azevedo (1997) (Figure 1), and incidence was assessed using a modified version of the method described by Haji et al. (2000). Leaves with active disease were assigned a score of 1, whereas leaves without symptoms or those considered recovered (no spores on the abaxial leaf surface) were assigned a score of 0. Leaves that had abscised were considered diseased and assigned 100% severity. The area under the disease progress curve (AUDPC) was calculated from incidence and severity data using the following equation:

$$AUDPC = \sum_{i=1}^{n-1} \left[\left(\frac{y_i + y_{i+1}}{2} \right) \mathrm{X} (t_{i+1} - t_i) \right],$$

where y1 and y2 are the values from two consecutive assessments at times t1 and t2, respectively.

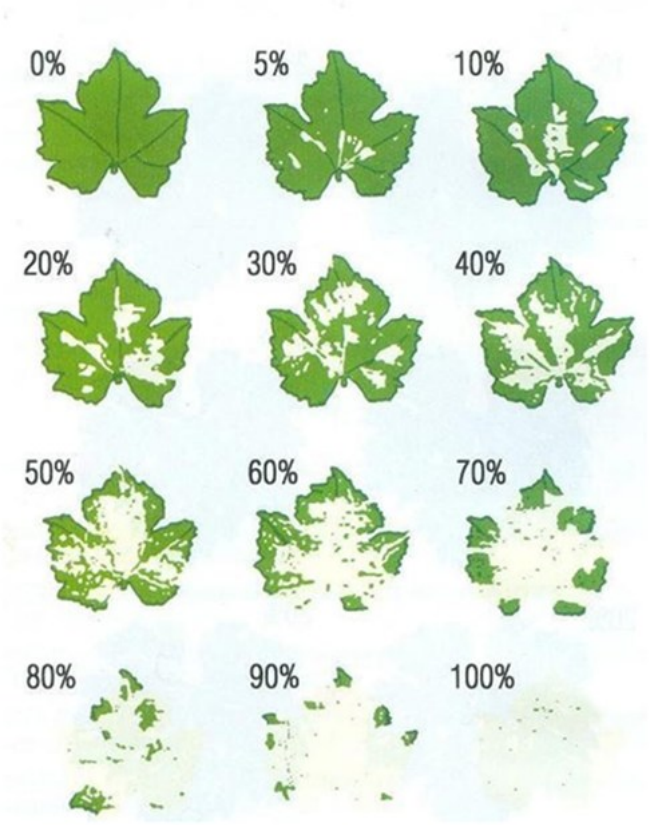


Figure 1. Diagrammatic scale used to assess grapevine downy mildew severity (AZEVEDO, 1997).

Statistical Analysis

Statistical analyses were performed in R (version 4.4.0; R Core Team, 2024) using the RStudio integrated development environment (version 2023.06.1; RStudio Team, 2023). All data were initially tested for normality (Shapiro–Wilk test) and homogeneity of variances (Bartlett's test) using the R package agricolae (version 1.3-7). Subsequently, treatment effects were assessed using analysis of variance (ANOVA), followed by Fisher's least significant difference (LSD) post hoc test. The Šidák correction was applied to sporangial germination data to control the type I error rate. Significant differences (p<0.05) were indicated by different lowercase and uppercase letters generated using the cld function of the R package multcomp (version 1.4-26); treatments sharing a letter were not significantly different.

RESULTS AND DISCUSSION

Compatibility of Twixx-A® with Fungicides

Twixx-A® was compatible with Forum®, Timorex Gold®, and Garra 450® WP, at all tested concentrations (Figure 2), as indicated by the absence of an inhibition zone around the disks and bacterial growth comparable to that in the control. These findings indicate that compatibility is influenced by several factors, including the active ingredient and application rate. Similarly, Santos et al. (2021) reported that the effects of chemical products on microorganisms depend on the active ingredient, the other components of the formulation, the application method, product mobility within the plant, and the microbial species involved.

In this assay, the formation of an inhibition zone indicates that the product is toxic to the microorganism, as the toxic substance diffuses into the medium from the paper disk, which absorbs water from the medium (KONEMAN et al., 2001).

Compatibility studies are essential for integrated disease management. Although tank mixing of chemical products may be recommended by an agricultural engineer on the basis of practical tests that primarily assess mixture homogeneity or physical properties relevant to spraying, mixtures involving biological products should only be prepared when specific studies have demonstrated their feasibility (GAZZIERO et al., 2021).

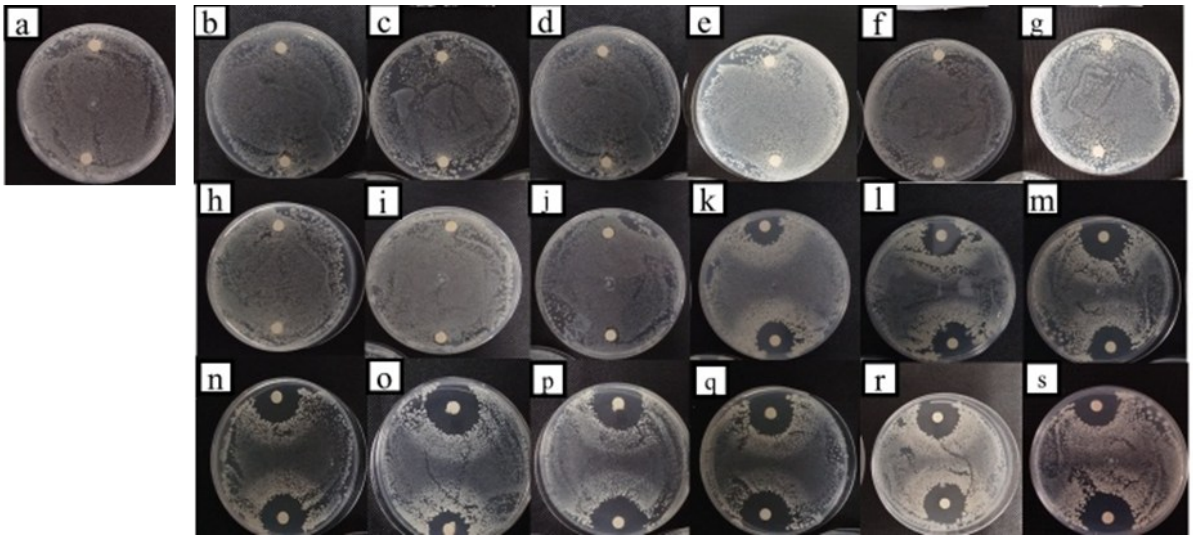


Figure 2. Compatibility test of Twixx-A® (*Bacillus amyloliquefaciens*) with fungicides at 50%, 100%, and 150% of the recommended rate. (a) Control. (b) Forum® 50%. (c) Forum® 100%. (d) Forum® 150%. (e) Timorex Gold® 50%. (f) Timorex Gold® 100%. (g) Timorex Gold® 150%. (h) Garra 450® WP 50%. (i) Garra 450® WP 100%. (j) Garra 450® WP 150%. (k) Manzate 800® 50%. (l) Manzate 800® 100%. (m) Manzate 800® 150%. (n) Ridomil Gold MZ® 50%. (o) Ridomil Gold MZ® 100%. (p) Ridomil Gold MZ® 150%. (q) Galben®-M 50%. (r) Galben®-M 100%. (s) Galben®-M 150%.

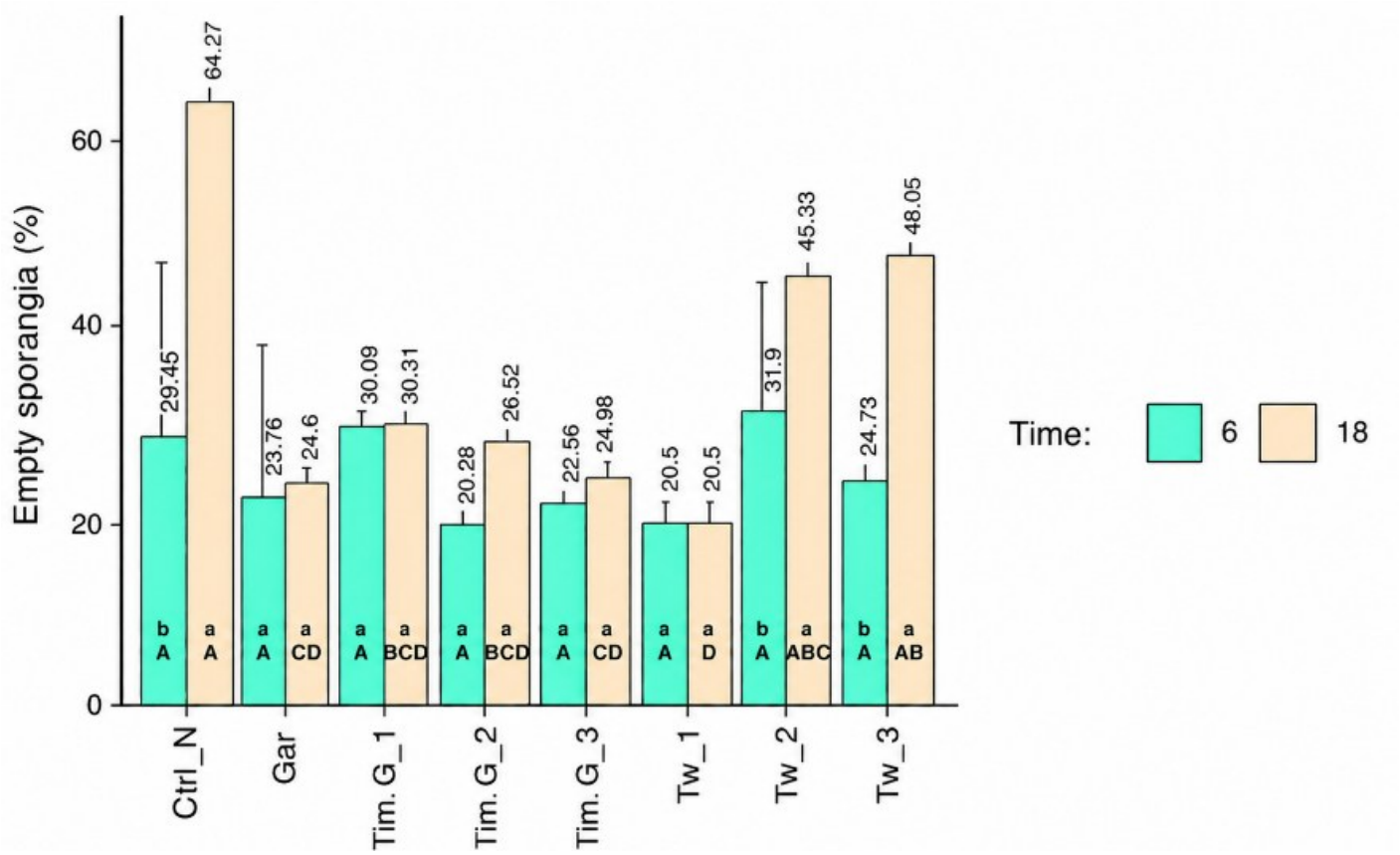
Twixx-A® was incompatible with Galben®-M (Figures 2q, 2r, and 2s), Ridomil Gold MZ® (Figures 2n, 2o, and 2p), and Manzate 800® (Figures 2k, 2l, and 2m), at all tested rates. However, inhibition-zone size does not necessarily indicate greater or lesser antimicrobial activity, because it depends on the rate of product diffusion through the medium rather than solely on the microorganism's sensitivity to the compound (KONEMAN et al., 2001).

The presence of mancozeb in Galben®-M, Ridomil Gold MZ®, and Manzate 800® may explain their incompatibility with Twixx-A®. Although mancozeb is registered for the control of fungi and oomycetes, Prabu, Umamaheswari and Rao (2018) observed an inhibitory effect on *B. amyloliquefaciens* IIHR BA2. Therefore, tank mixing these fungicides with products containing *B. amyloliquefaciens* strains is not recommended because they may inactivate the antagonistic agent, unless prior compatibility tests have demonstrated otherwise.

Understanding compatibility and its underlying mechanisms is important because, in some cases, an apparently favorable interaction may result from biodegradation of the chemical pesticide. This can reduce its effectiveness against the target pest and increase the need for repeated applications (PUJAR et al., 2022), contributing to resistance development, environmental contamination, and higher management costs.

Assessment of the Percentage of Empty Sporangia

The percentage of empty sporangia after 6 h of incubation did not differ significantly among treatments (p<5%; Figure 3). However, after 18 h of exposure, Timorex Gold® (*M. alternifolia*) at 1, 2, and 3 mL L^{-1} and Twixx-A® (*B. amyloliquefaciens*) at 1 mL L^{-1} resulted in 30.31%, 26.52%, 24.98%, and 20.5% empty sporangia, respectively. These values did not differ significantly from that of the positive control, Garra 450® WP (24.6%), and represented a reduction of more than 69% in the number of empty sporangia, with significant differences from the negative control (64.27%) (Figure 3). Fewer empty sporangia indicate fewer released zoospores, thereby reducing the likelihood of new infections.



Bars represent means, and vertical lines indicate the corresponding standard deviations above the means. Means followed by different lowercase letters within the same treatment or different uppercase letters at the same assessment time differed significantly according to Fisher's LSD test (p<0.05). Ctrl_N: negative control; Gar: Garra 450® WP; Tim.G_1, Tim.G_2, and Tim.G_3: Timorex Gold® at 1, 2, and 3 mL L^{-1}, respectively; Tw_1, Tw_2, and Tw_3: Twixx-A® at 1, 2, and 3 mL L^{-1}, respectively.

Figure 3. Mean percentages of empty sporangia by treatment and assessment time.

Fialho et al. (2017) also observed an inhibitory effect of *M. alternifolia* essential oil on *P. viticola* germination. After incubating sporangia in culture medium supplemented with *M. alternifolia* essential oil, they found that a concentration of 4% completely inhibited germination after 6 h. This effect was statistically similar to that of mancozeb + metalaxyl-M (640 + 40 g a.i. kg^{-1} of commercial product) at a concentration of 0.5% over the same period and to the effects observed at oil concentrations of 2% and 4% after 12 h. The authors also reported a fungistatic effect of the oil, potentially associated with its chemical instability. Such an effect was not observed in the present study, possibly because a more stable commercial formulation was used.

The essential oil of *M. alternifolia* leaves is rich in terpinen-4-ol, which may account for as much as 40.3% of its composition (BOROTOVÁ et al., 2022) and is considered the main compound responsible for its antimicrobial properties (MONDELLO et al., 2006). Deweer, Sahmer and Muchembled (2023) demonstrated these properties by evaluating the effects of the essential oil and isolated terpinen-4-ol against the oomycete *Phytophthora infestans* and observing comparable levels of activity.

The reduction in the percentage of empty sporangia following treatment with *B. amyloliquefaciens* at 1 mL L^{-1} (20.5%; Figure 3) is consistent with the findings of Michel and Cavalcanti (2020). These authors also reported favorable results from direct-contact assays with *B. subtilis* at 125 mL L^{-1} and *B. amyloliquefaciens* strain D-747 at

2.5 mL L^{-1}, which inhibited zoospore release from sporangia. However, they observed that *B. subtilis* at 1 mL L^{-1} stimulated zoospore release, emphasizing that the efficacy of these microorganisms may vary with species, strain, and concentration.

Regarding the effect of exposure time, the percentages of empty sporangia after 6 and 18 h did not differ significantly for Timorex Gold® at any of the three tested concentrations or for Twixx-A® at 1 mL L^{-1} (Figure 3). This may indicate a more persistent effect on the pathogen or greater lethality. In contrast, Twixx-A® at 2 and 3 mL L^{-1} showed a pattern similar to that of the control, with a significant increase in empty sporangia over time. This pattern may suggest a fungistatic effect of *Bacillus* strains at higher concentrations, possibly associated with competition: as resources in the medium become limited over time, viable bacterial cell numbers and concentrations of inhibitory compounds decline, allowing zoospore release to resume.

Field Trial: *In Vivo* Control of Downy Mildew

Under the conditions evaluated, no statistically significant differences among treatments were detected for downy mildew severity, incidence, or the area under the disease progress curve (AUDPC) for either variable (p>0.05; Table 2).

Table 2. Analysis of variance (ANOVA) for grapevine downy mildew incidence, severity, the area under the incidence progress curve, and the area under the severity progress curve by treatment.

Incidence					
Source of variation	DF	SS	MS	F	*p*-value
Block	3	810.37	270.12	1.49^{ns}	0.2583
Treatment	5	2042.86	408.57	2.25^{ns}	0.1027
Residual	15	2724.58	181.64		
Total	23	5577.81			
CV (%)					18.03
Severity					
Source of variation	DF	SS	MS	F	*p*-value
Block	3	116.63	38.88	0.92 ^{ns}	0.4575
Treatment	5	192.12	38.42	0.90 ^{ns}	0.5039
Residual	15	637.66	42.51		
Total	23	946.41			
CV (%)					33.90
AUDPC - Incidence					
Source of variation	DF	SS	MS	F	*p*-value
Block	3	169771.70	56590.57	0.92^{ns}	0.4556
Treatment	5	419371.48	83874.30	1.36^{ns}	0.2931
Residual	15	924043.42	61602.90		
Total	23	1513186.60			
CV (%)					10.17
AUDPC - Severity					
Source of variation	DF	SS	MS	F	*p*-value
Block	3	5638.51	1879.50	0.36 ^{ns}	0.7859
Treatment	5	13432.06	2686.41	0.51 ^{ns}	0.7658
Residual	15	79294.34	5286.29		
Total	23	98364.91			
CV (%)					22.63

CV = coefficient of variance; DF = degrees of freedom; SS = sum of squares; MS = mean square; F = F-statistic; p = *p*-value. AUDPC = area under the disease progress curve.
ns: not significant according to the F-test (p>0.05).

The lack of treatment-related reductions in the epidemiological variables may be related to the timing of application, which began after infection had occurred and symptoms were visible, or to the application frequency. As Zhang et al. (2017) noted, applying biological control agents (BCAs) before disease onset is important for effective control, because it allows the agents to colonize leaf tissues and secrete antibiotic compounds before the pathogen becomes established.

Cavalcanti, Cassuba and Fioravanço (2020) observed positive effects of *Bacillus subtilis* and *Bacillus amyloliquefaciens* on the control of grapevine downy mildew

when applied at similar concentrations (2 mL L^{-1} and 2.5 g L^{-1}, respectively) every four days. These treatments produced significantly lower AUDPC values than the untreated control, although their performance did not match that of Bordeaux mixture.

The *in vivo* findings of the present study differ from those of Michel and Cavalcanti (2020), who evaluated *Bacillus subtilis* and *B. amyloliquefaciens* strain D-747 on artificially inoculated 'Cabernet Sauvignon' grapevines grown in a greenhouse. Although the biological agents did not provide complete protection against infection, they delayed disease progression and defoliation following both foliar and substrate applications. In that study, *B. subtilis* applied to the substrate at 2 mL L^{-1} provided protection, while foliar application of *B. amyloliquefaciens* at 2.5 mL L^{-1} achieved the greatest disease control. The latter was the only treatment whose level of control did not differ significantly from that of Bordeaux mixture (0.5%). The authors reported that the activity of biological control agents is not necessarily dependent on direct contact with the pathogen and that the most effective application method and concentration may vary substantially among species.

Although tea tree oil did not produce promising results in the *in vivo* trial conducted here, its effectiveness against fungi and oomycetes has been reported under other conditions and in other pathosystems. In experiments with *Bremia lactucae*, Reuveni and Cohen (2020) showed that Timorex Gold® had a greater effect on mycelial development and sporophore formation than on spore germination, and was more effective after pathogen penetration. This effect was associated with the oil's ability to penetrate host tissues and the intracellular spaces of the leaf mesophyll (CARSON; MEE; RILEY, 2002).

A notable feature of the study by Reuveni and Cohen (2020) was the higher application frequency, which may limit product use because of the associated cost. Nevertheless, this finding supports further studies: despite the increased cost, the product may be a viable option close to harvest, when residue concerns restrict the use of conventional products.

CONCLUSIONS

The compatibility of *Bacillus amyloliquefaciens* with Forum® (dimethomorph), Garra 450® WP (copper hydroxide), and Timorex Gold® (*Melaleuca alternifolia*) provides information for developing integrated disease management protocols in crops where these products are used.

However, given the absence of statistically significant effects in the field trial, even for products that performed satisfactorily *in vitro*, further studies should evaluate preventive applications or conditions with lower disease pressure, as well as different rates, application intervals, and crop growth stages.

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