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New problems for old vineyards: Mitigating the impacts of yellow-legged hornets (*Vespa velutina*) in a historical wine-producing area

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ABSTRACT

Traditional small-sized vineyards are especially sensitive to different impacts, including the arrival of new pests. The adults of the yellow-legged hornet (*Vespa velutina*), an invasive alien species present in the Iberian Peninsula since 2010, feed on sugary foods, causing crop losses in vineyards. However, present management techniques for the control of *V. velutina* are limited, and they do not provide effective control in agricultural settings. This work aims to evaluate the use of an exclusion system in a traditional non-mechanized vineyard of a highly invaded area by *V. velutina* in NW Spain (Protected Geographical Indication of Betanzos, Galicia) as a method to mitigate the damage caused by hornets. Anti-hail nets were used in a factorial design experiment with groups of netted and unnetted vines of two white wine cultivars in order to address the vineyard production loss. In particular, we aim to 1) asses the effectiveness of anti-hail netting on preventing grape yield loss, 2) assess the impact of anti-hail netting on grape ripening and incidence of bunch fungal infection, and 3) study the potential relationship between the damage caused by *V. velutina* and grape fungal diseases. Results show that the tested exclusion system increases the crop yield, since it prevents effectively both the damage caused by hornets and birds. No significant correlation between the damage caused by *V. velutina* and the incidence of bunch fungal diseases was found in either cultivar. However, netting increased slightly the final sugar content in one of the cultivars, as well as the incidence of bunch fungal damage. We discuss the management implications of this exclusion method within the framework of agricultural land abandonment and the loss of traditional landscapes.

1. Introduction

Agriculture land abandonment has been highlighted as a widespread phenomenon in many areas of the world, notably in Europe (Levers et al., 2018), leading to the loss of traditional rural landscapes, cultural ecosystem services as well as biodiversity and historical values (Rey Benayas et al., 2007, Slámová and Belčáková, 2020). These problems are common to wine producing areas, which face the loss of the unique character of vineyard landscapes (Lieskovsky et al., 2013). Small-sized vineyards, which have maintained traditional management, are especially sensitive to changes (Wyler et al., 2023, Lieskovský and Kenderessy, 2022), and different factors, from spatial megatrends (Debonne et al., 2022) to local threats (Calafat-Marzal et al., 2023) may accelerate the complete abandonment of areas traditionally dedicated to vineyard cropping.

According to the seminal work *Vignobles et vins du Nord-Ouest de l'Espagne* by Huetz de Lemps (1967), wines from NW Spain were renowned and an important trade item in Middle Ages. One of the most significant wine-growing areas was Betanzos (Galicia, NW Spain), where written records of the existence of vineyards date back to the 9th century. However, the extension of vineyards got progressively reduced in this area, with a remarkable turning point in the 19th century with the arrival of fungal diseases, as well as the phylloxeric plague. This, together with migratory movements to urban areas during the second half of the 20th century, led to the almost complete abandonment of vineyards in the area (Martínez et al., 2012), with a present cultivation extension under 10 ha.

Interestingly, in recent decades there has been an increasing interest in recovering abandoned or disused wine varieties in different wine-producing regions, driven by new actors who focus on the quality of the wine (Crespo-Martínez et al., 2022) but also on their environmental, cultural and heritage value (Baraja et al., 2019, Baraja and Herrero, 2020). In Betanzos, viticulture has become one of the productive agricultural activities that currently gives rise to different economic and

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cultural initiatives (Gago et al., 2011, Togores-Hernani et al., 2020, López-Vicente et al., 2023). But wine producers are facing a new problem: the invasion of the yellow-legged hornet *Vespa velutina* Lepeletier, 1836 (Hymenoptera, Vespidae).

Damage caused by wasps and hornets in vineyards is well known. For example, Matsuura and Yamane (1990) provide data on the damage caused by *Vespa* species in Japanese orchards and vineyards, and review damages caused also in Europe. Guedot et al. (2018) studied the phenology of different wasp species attacking vineyards in the USA, while Oliveira et al. (2019) characterised wasp communities causing losses in vineyards in Brazil. Wasps can behave either as opportunists, taking advantage of wounds caused on grapes by other organisms (Galvan et al., 2008), or by inflicting direct damage to berries (Cranshaw et al., 2011). This causes wounds that can be used as an entry point by other organisms, such as fungal pathogens, causing significant grape yield loss (Barata et al., 2012). Also, wasps themselves could act as vectors for the transmission of diseases (Madden et al., 2017).

The invasion of *V. velutina,* which is present in Europe since 2004 and in the Iberian Peninsula since 2010*,* is causing significant ecological, social and economic impacts in different invaded areas (Vidal et al., 2019, Barbet-Masin et al., 2020, Rojas-Nossa and Calviño-Cancela, 2020, Laurino et al., 2020, Rome et al., 2021, Feás et al., 2022). The main economic damage is associated with their feeding habits, and the beekeeping sector is severely affected due to *V. velutina* predation on honeybees and the consequent loss of colonies (Monceau et al., 2012, 2014, Monceau and Thiéry, 2017, Requier et al., 2019, Laurino et al., 2020, Requier et al., 2023). Adult hornets feed also on carbohydrates obtained from different sources (flower nectar, tree sap or various fruits) (Monceau et al., 2014, Rome et al., 2015), causing damages in fruit yields such as apples, pears or grapes (Matsuura and Yamane, 1990).

A recent report on the impact of *V. velutina* in wine farms in Galicia (NW Spain) shows that wine producers consider the damage increased as the presence of the species raised in the last decade, as well as that bites on the fruit favour the appearance of other diseases, such as grey mould or other bunch rot (García-Arias et al., 2022), and there is a growing interest in implementing protection systems against this invasive species. However, currently available wasp management techniques are limited and include treatment or removal of nests, sanitation of damaged grapes and bunches, or trapping with baits (Guedot et al., 2018), but these methods do not provide effective control in agricultural settings (Landolt and Zhang, 2016), and interaction with other grape yield loss causal agents, such as birds or fungi has not been tackled.

Exclusion nets are intended to protect crops from different types of physical damage, including injuries caused by biotic (birds, insects) or abiotic factors (hail, frost, wind, sun radiation). They are frequently used in tree fruit production (Tasin et al., 2008, Chouinard et al., 2019, Manja and Aoun, 2019), but also in small fruit crops (Kuesel et al., 2023) and vineyards (Muntean, 2018, Ebbenga et al., 2019, Leach et al., 2023). Thus, the aim of this study is to address the vineyard production loss and to evaluate the performance of an exclusion system using anti-hail netting as a method to mitigate *V. velutina* damage in a historical vineyard in Galicia (NW Spain). Specific objectives include: 1) assessing the effectiveness of anti-hail netting on preventing grape yield loss by *V. velutina* in two white grape cultivars; 2) assessing the impact of anti-hail netting on grape ripening and incidence of bunch fungal infection, and 3) studying whether there is a relationship between the damage caused by *V. velutina* and grape fungal diseases.

2. Material and methods

2.1. Study area

The Protected Geographical Indication (PGI) of Betanzos is an EU differentiated quality label for wines produced in five municipalities located in the province of A Coruña (Galicia, NW Spain) (Fig. 1). This northwest zone of the region has been reported as one of the areas with the highest densities of *V. velutina* nests in Europe (up to 17.1 nests/km^2 according to Pazos et al., 2022) although requests for nests to be removed by the regional administration in these municipalities differ among them and vary from year to year (Fig. 2), probably depending on landscape factors and weather conditions (Rodríguez-Flores et al., 2019). The climate of this area is temperate oceanic with Mediterranean influence, with mild and rainy winters and cool summers (Martínez et al., 2012, López-Vicente et al., 2023).

The vineyard in which the study was carried out is located in the municipality of Paderne (43.295774, −8.173406, WGS84 datum) (Fig. 1), and it is managed by "Pagos de Brigante" winery under organic farming. The area presents a mixed landscape of agricultural and forestry exploitations, with main land uses of eucalyptus plantations, grazing meadows and other minor uses such as herbaceous crops, native hardwood formations and tree or shrub crops. The selected vineyard has a total area of approximately 1.44 ha, with vines trained in vertical trellis (Fig. 3) that include two white wine grape cultivars: Blanco Lexítimo (BL) and Godello (G). Weeds are controlled without herbicides, with cover crops including a mixture of legumes and crucifers between the trellises.

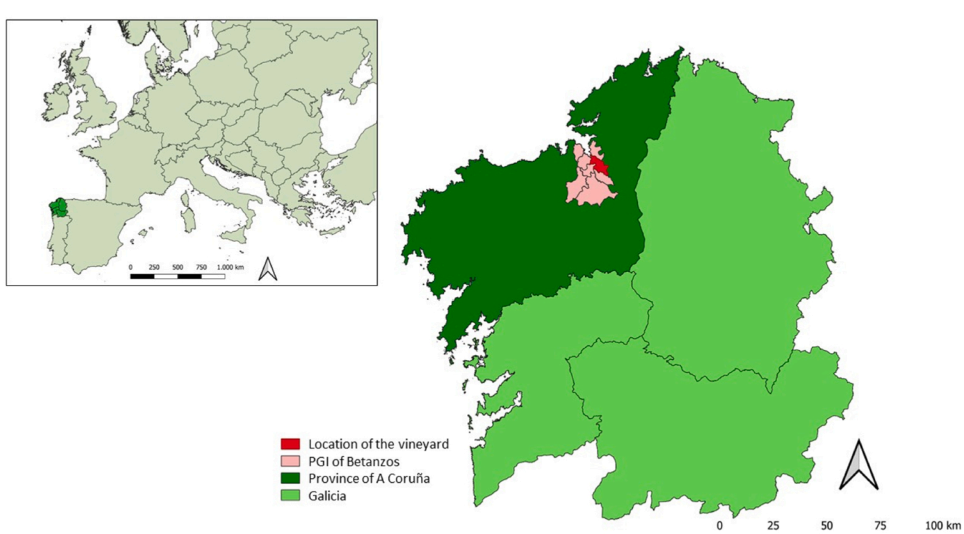

Fig. 1. Location of the PGI of Betanzos in the autonomous region of Galicia (NW Spain).

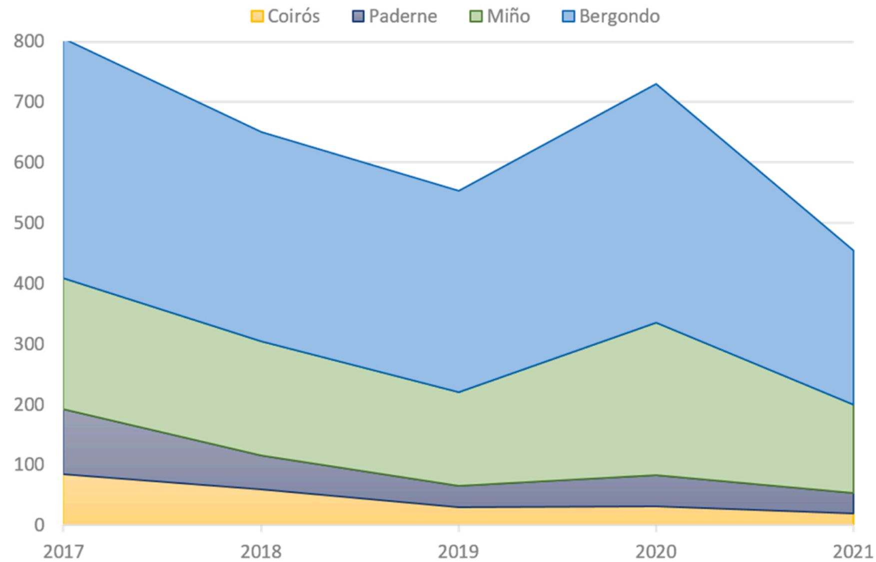

Fig. 2. Number of requests received by the regional administration for nests to be removed per year (2017–2021) in four out of the five municipalities belonging to the PGI of Betanzos. Data provided by the regional administration (Xunta de Galicia).

Fig. 3. Nets installed in part of the vineyard covering groups of trellised vines.

Common fungal diseases such as grey mould (caused by *Botrytis* spp.), powdery mildew (caused by *Erysiphe necator* Schwein., (1834)) or downy mildew (caused by *Plasmopara viticola* (Berk. & Curt.) Berl. & de Toni 1888) decrease the grape yield and quality in the region, which obliges producers to apply penetrating and systemic treatments periodically according to the pathogen's intensity (Cortiñas Rodríguez et al., 2020). However, local wine producers have reported important damages in their crops caused by *V. velutina*, as well as by birds, but till present none of them have tried to quantify grape yield losses.

2.2. Experimental design

The experiment was carried out in 2021 between July 29, when the anti-hail nets were installed, and September 22, when they were removed for the harvest. The damage produced by *V. velutina* occurs after veraison (beginning of grape ripening), which in the experimental vineyard usually occurs during the first half of August. To protect the grapes against both birds and hornets, an exclusion system with a 1.4 mm × 1.4 mm mesh-size anti-hail net was used, in a factorial design experiment with groups of covered and uncovered vines of the two white wine cultivars (BL and G) (Fig. 3).

In order to avoid potential effects derived from possible different levels of contact between the net and the plant and the fruit, groups of 3 vines were covered with net, in which data were only taken from the central vine. All central vines used in the experiment were of similar vigour and presented a minimum of 5 clusters when the net was installed. In total, 22 groups of each cultivar were covered, while 28 groups of BL and 27 groups of G of the remaining uncovered groups were considered for comparison (for the computation of the sample size, see Data processing and statistical analysis section).

To assess whether using anti-hail nets affects the grape ripening process, we measured sugar content both at the time of installation and removal of the nets. Three clusters were randomly selected from each central vine following Tracey and Saunders (2010) and, using a hand refractometer, sugar concentration (°Bx) of three random grapes from each of the three randomly selected bunches was measured and the mean was calculated.

To assess grape yield loss caused by *V. velutina*, birds and fungi at the moment of harvest, visual estimates were made of the percentage of damaged clusters by the three causal agents separately, measured in 10%-intervals. The correct identification of each causal agent was ensured by recording the progress of damage by birds and hornets each three days in nine selected bunches during a period of three weeks before the harvest (Fig. 4). Grapes in the selected vineyard were attacked by birds that ate the whole berries, allowing discrimination with berries bitten by hornets. From each central vine, three bunches were randomly selected, again following Tracey and Saunders (2010), and the percentage of damage produced in each bunch by each organism

Fig. 4. Progress of the damage caused by *V. velutina* from first (September 10, 2021) to last recording date (September 22, 2021). Missing grapes at the tip of the bunch were eaten by birds.

was noted and averaged to obtain a single value for each vine. It should be noted that, throughout the experiment, the only wasps or hornets observed on the bunches were *V. velutina*.

The grape yield loss in weight (g) per vine in uncovered plants with respect to covered vines, due to *V. velutina* and birds separately, was calculated as follows. The weight of grapes in covered vines was measured at harvest for BL and G. Grapes damaged by fungi (approximately 11.8% for BL and 25.1% for G after visual estimates, see Table 1) are removed by producers before weighing the bunches. Therefore, the measured harvest weight represents 88.2% for BL and 74.9% for G. Note that if the vine was not covered, there would be grapes damaged by *V. velutina* and grapes eaten by birds (see Table 1). As a consequence, not covering the vine would imply a loss at harvest by causal agent (*V. velutina*, birds) equal to the weight of grapes in covered vines (g) × grapes damaged by causal agent (%) / weight of grapes not damaged by fungi (%).

2.3. Data processing and statistical analysis

Sample size calculation was performed using G*Power 3.1 software. Results indicated the need to have a sample of at least 48 vines in total to be able to detect, by means of a one-factor fixed-effect ANOVA, an effect size equal to 0.56 of the treatment (covered or uncovered vine) on the percentage of damaged bunch, with a significance level $\alpha = 0.05$ and power $1\text{-}\beta = 0.95$. An effect of 0.56 corresponds to a decrease in the percentage of damage from 30% in uncovered plants to 13% in covered plants (standard deviation 15%).

This sample size calculation assumes complete independence among samples. In our case, the level of independence might be not complete because all vines are located in the same vineyard. However, we prioritized this single-vineyard design for a first assessment of *V. velutina* damage in order to minimize variability on the measured variables caused from uncontrolled factors, either biotic factors (e.g., presence of other species of wasps in different vineyards that might alter damage percentages) to abiotic (e.g., differences in soil characteristics, water availability, sun orientation or even vine ages can deeply impact sugar content).

Statistical analyses were carried out using R software version 4.1.2 and the integrated development environment RStudio version 4.1.2 (www.rstudio.com). The effect of nets on the potential grape yield loss caused by fungi was studied using a one-factor ANOVA model for each grape variety (BL and G) after testing for normality. In the case of *V. velutina* and birds, where damage in netted vines was inexistent and values were consistently equal to zero, a one-sample t-test and a one-sample Wilcoxon test were used for normal and non-normal data respectively. In addition, Spearman's correlation coefficient was used to assess the potential correlation between *V. velutina* damage and that caused by fungal diseases (both measured as percentages). Finally, an ANCOVA model was used to investigate whether the treatment affects the final sugar content of grapes depending on the initial content, also separately for each grape variety. Anomalous measures in sugar content at harvest time due to ripening delay in some grapes (outlier values for final sugar content) were not used in the analysis (three in BL, one in G), since random selection did not prevent the presence of aberrant unripe grapes (see 2.2. Experimental design).

Table 1
Mean (± SD) percentage of visually observed damage caused by *V. velutina*, fungi or birds in both treatments for Blanco Lexítimo and Godello cultivars.

Cultivar	Causal agent	Damage estimates (%) on bunches		
		Covered	Uncovered	*p*-value
Blanco Lexítimo				
	Vespa velutina	0.0 ± 0	10.9 ± 8.5	< 0.001#
	Fungal diseases	21.2 ± 14.3	11.8 ± 9.6	0.018+
	Birds	0.0 ± 0	64.3 ± 33.6	< 0.001§
Godello				
	Vespa velutina	0.0 ± 0	11.9 ± 8.5	< 0.001§
	Fungal diseases	22.9 ± 19.9	25.1 ± 17.1	0.701+
	Birds	0.0 ± 0	7.3 ± 13.6	0.007§

#One-sample t-test. +One-factor ANOVA model. §One-sample Wilcoxon test.

3. Results

Monitoring of the bunches showed that the damage caused by birds started earlier (before veraison) than damage by *V. velutina*, and it can be locally important, as for BL cultivar in this study. Grapes damaged by *V. velutina* are bitten and deteriorate progressively (Fig. 4).

The installation of anti-hail nets prevents the access of wasps and birds to the fruit (Fig. 5, Table 1), reducing significantly the grape yield loss both in BL (*V. velutina:* $p < 0.001$; birds: $p < 0.001$) and G (*V. velutina*: $p < 0.001$; birds: p = 0. 0.007) (Table 1). Regarding losses caused by fungal diseases, no statistically significant differences were found between covered and uncovered vines of G ($p = 0.701$), but significant differences were found in BL ($p = 0.018$), with significantly higher fungi damage in covered vines (Table 1).

Spearman's correlation coefficient shows that there is no significant correlation between the damage caused by *V. velutina* and the visually observed incidence of fungi, neither in BL ($r = 0.013$, $p = 0.506$) nor in G ($r = 0.028$, $p = 0.291$).

As for the potential influence of anti-hail nets on the ripening process and the final quality of grapes, netting increased slightly final sugar content (see data set in Supplementary material and Table 2). This increment was statistically significant for BL variety (mean sugar content of covered vines: 21.2 °Bx, mean sugar content of uncovered vines: 20.1 °Bx; $p = 0.01$) but ANCOVA test did not find statistically significant differences in the final sugar content for G variety (mean sugar content of covered vines: 17.4 °Bx, mean sugar content of uncovered vines: 16.6 °Bx; $p = 0.389$) (Fig. 6).

The grape yield loss in weight (g) per vine in uncovered plants with respect to covered vines, due to *V. velutina* and birds separately, differed between BL and G cultivars (Table 3).

The observed mean difference in the weight of grapes between covered and uncovered vines shows that the total losses caused by *V. velutina* and birds, estimated from the visual observation of the percentage of damaged bunches, are close to the real losses registered during the harvest for both BL (121.79 g estimated *vs.* 125.92 g observed) and in G (84.38 g estimated *vs.* 96.21 g observed) (Table 3).

4. Discussion

Wasps and hornets are known to bite grapes for feeding, and this study provides a first evaluation of *V. velutina* damages on vineyards.

Outcomes of wasps feeding behaviour can be complex. For example, paper wasps are known to transport yeast relevant for wine-making from nearby forest areas to vineyards (Valentini et al., 2022) and may even contribute to restore important mycobiota in these crops (Di Paola et al., 2023). However, Vespidae species are also considered as pests because of the yield losses they cause (Vincent et al., 2018). Thus, diverse authors have tried to provide estimates of the economic costs caused by *V. velutina* in invaded areas, particularly those associated to its control (Barbet-Masin et al., 2020, Pazos et al., 2022) or its impact on beekeeping (Requier et al., 2023). Yet, Angulo et al. (2021) highlight that damage costs of invasive alien species are mostly missing, which hampers the assessment of management effectiveness.

Our study provides a first assessment of grape yield loss caused by *V. velutina* in two white wine cultivars in a historical vineyard, which amounts, on average, ca. 11% of the bunch grapes in our experiment. Vineyard plots in this region are small and surrounded by a complex landscape. These factors, from cultivar to plot size and location, can determine the impact of *V. velutina*. For example, insect infestation is influenced by cluster and texture features of fruits and berries (Matsuura and Yamane, 1990, Fermaud, 1998, Tonina et al., 2020), but differences in landscape can also shape the potential density of *V. velutina* colonies

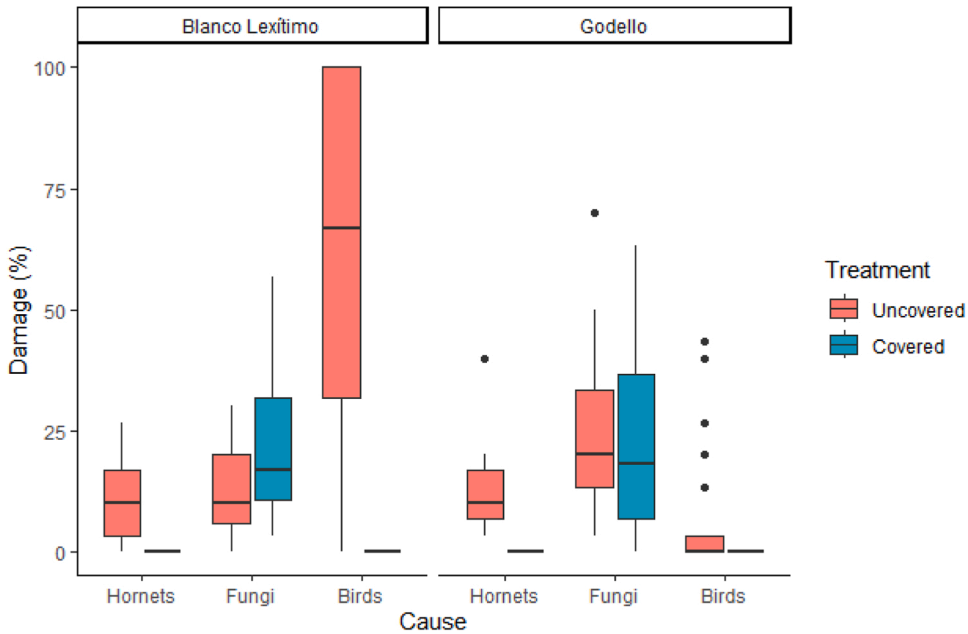

Fig. 5. Percentage of damage recorded for *V. velutina*, fungal diseases and birds in the Blanco Lexítimo and Godello cultivars in both treatments.

Table 2
Mean (± SD) of initial and final sugar content (°Bx) in both treatments for Blanco Lexítimo and Godello cultivars.

Cultivar	Initial sugar content (°Bx)			Final sugar content (°Bx)		
	Total	Covered	Uncovered	Total	Covered	Uncovered
Blanco Lexítimo	4.3 ± 0.9	4.4 ± 1.1	4.1 ± 0.5	20.7 ± 1.6	21.2 ± 1.5	19.7 ± 1.2
Godello	3.9 ± 0.4	3.8 ± 0.4	4.0 ± 0.5	16.9 ± 2.0	17.4 ± 2.5	16.6 ± 1.6

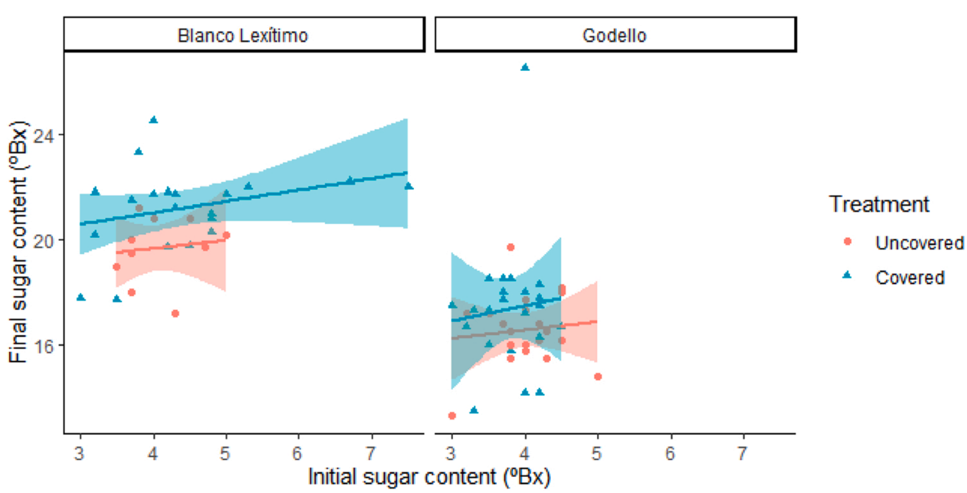

Fig. 6. Initial and final sugar content (°Bx) in Blanco Lexítimo and Godello vines in both treatments (anomalous values excluded).

(Monceau and Thiéry, 2017) and their access to vineyard plots (Poidatz et al., 2018).

Apart from the yield loss, wounds caused by hornets in grapes might affect the quality of the final product. The connection between grape quality and fungal disease can be complex, as it depends on the integrity of the grape skin, but also on the berry development stage or the prevailing environmental conditions (Loureiro et al., 2012). In this study we could not find a significant correlation between the damage caused by *V. velutina* and the incidence of bunch fungal diseases by visual estimation, although wasps have been reported to facilitate bunch susceptibility to them (Madden et al., 2017). As stated by Barata et al. (2012), the health status of grapes is the main factor affecting their microbial ecology, and high damages are expected to increase both numbers and diversity of microbes. These changes may have an impact on the ripening and fermentation of grapes and the final wine traits, thus adding a potential side-effect of *V. velutina* grape damage to wine producers.

The use of exclusion nets prevents the access of *V. velutina* to the bunches, as well as of birds, reducing grape yield loss. Netting is already a common method to protect fruit against hail (Muntean, 2018) or

Table 3
Observed and estimated loss of grapes per vine at harvest in the studied cultivars.

Cultivar	Weight of grapes in covered vines	Weight of grapes in uncovered vines	Loss at harvest for uncovered vines		
Blanco Lexítimo				Estimated	Observed
	142.84 ± 58.15 g	16.9 ± 27.76 g	*V. velutina*	17.62 g	
			Birds	104.17 g	
			Total	121.79 g	125.92 g
Godello	329.17 ± 236.11 g	232.96 ± 67.39 g			
			V. velutina	52.32 g	
			Birds	32.06 g	
			Total	84.38 g	96.21 g

different plagues like birds (Pagay et al., 2013, Lindell et al., 2018, Micaelo et al., 2023) but it has been also tested in vineyards for invasive insects such as the spotted lanternfly (*Lycorma delicatula* (White, 1845)) (Leach et al., 2023).

Although we provide yield losses estimates in unnetted vines, in our experimental setting we cannot discard a potential spillover effect of the net on the adjacent vines. Given that the net is a non-lethal control technique with a specific location on the covered vine, the adjacent vines without the net might have increased damage and thus the overall benefit of the net on a vineyard scale could be weakened, both for hornets and birds. Also, overall benefit could be lower because damage by birds can be higher in the edges than in the center of vineyards (Somers and Morris, 2002). These factors should be taken into account when assessing the cost-benefit of netting.

In an attempt to reduce damages in vineyards, wine producers in our study area have relied on a scattered use of liquid-baited traps for capturing founder queens of *V. velutina* in spring as well as *V. velutina* workers during the grape ripening period in late summer, when colonies are at their highest activity. However, the use of these traps has been discouraged by many authors due to their high bycatch and potential impact on some insect populations (Rome et al., 2011, Rojas-Nossa et al., 2018, Lioy et al., 2020, Requier et al., 2020, Sánchez and Arias, 2021), and producers acknowledge limited results of trapping campaigns. Indeed, producers declare that the ineffectiveness of control methods and the economic losses caused by *V. velutina* in the last decade are a perfect breeding ground for frustration and potential abandonment of the vineyard.

Anti-hail nets used in this work reduce grape yield loss caused by wasps and birds. However, potential drawbacks can outweigh the advantages of netting in small historical vineyards.

First, producers must make economic decisions on net installation and face investment costs with uncertainties on their potential return. Reducing uncertainty requires a temporal series of data on grape yield loss, unavailable for *V. velutina* at present, as this is the first study to provide data on losses by the species. Thus, the economic cost and the changes that net installation can cause in the traditional management of the vineyard will influence the degree of acceptance by small winegrowers such as those of the PGI of Betanzos. Indeed, workload and management difficulties have been reported to play an important role in the decision of winegrowers to give up their activity in other areas (Wyler et al., 2023). Also, despite there seems to exist a growing interest in the development of non-lethal crop protection strategies against different organisms (Sausse et al., 2021), difficulties in the degree of mechanization required for net installation may lead producers to reject this method, relying on the much less efficient, but extremely cheap, liquid-baited traps.

Second, netting may alter the microclimate conditions into the canopy and affect the ripening process and the incidence of bunch fungal diseases, although results of previous netting experiments using shading or anti-hail nets in other areas have yielded contradictory results. For example, Ghiglieno et al. (2020) reported delaying ripening when using shading nets for cultivars suitable to produce sparkling wine, while Leach et al. (2023), in an experiment using anti-hail nets, reported no effects of netting on fruit quality (total soluble solids, pH and titratable acidity). Our results showed significant increase of sugar content in netted Blanco Lexitimo grapes, but not in Godello. Similarly, only netted Blanco Lexitimo vines showed a significant increase of fungal damage. Thus, potential impacts of different types of netting in the chemical and organoleptic properties of wines should be assessed in detail, as impacts and commercial consequences may depend on the cultivar.

Finally, net installation in historical vineyards may face also challenges derived from the visual impact of plastic nets in the landscape, as well as the sustainable use of these plastic residues (Hofmann et al., 2023). Importantly, changes in management and farming intensification are thought to affect biodiversity (Puig-Montserrat et al., 2017, Assandri et al., 2017), which is not negligible providing that an important 'quality label' of the area is their inclusion in a Biosphere Reserve (Mariñas Coruñesas e Terras do Mandeo Biosphere Reserve). However, no wine or biodiversity tourism activities in vineyards will be possible if yield losses by *V. velutina* force producers to abandon their crops.

5. Conclusions

The ineffectiveness of *V. velutina* control methods and the economic losses caused by this invasive hornet in an historical wine-producing area in NW Spain are acknowledged by producers as an important factor that may lead to the abandonment of vineyards. The use of anti-hail netting in our study site increased the crop yield in two white wine cultivars (Blanco Lexítimo and Godello), showing optimal performance for the protection of vines against wasps and birds. Netting increased also the incidence of bunch fungal damage and the final sugar content of grapes in one of the cultivars, but further studies should be performed as the potential influence of factors such as orientation, proximity to the sea, soil acidity, etc. cannot be ruled out. Despite these limitations, the advantages of using exclusion nets could offset the cost in years and areas especially affected by wasps and birds, and they may be an appropriate alternative for the protection of vineyards against *V. velutina*. Acceptance by producers might be hampered, however, by factors such as the uncertainties on the potential return of their economic investments, so this study provides an initial evidence base that could be expanded in future studies.

CRediT authorship contribution statement

María J. Servia: Writing – review & editing, Supervision, Conceptualization. **María Amalia Jácome:** Visualization, Methodology, Formal analysis. **Yaiza R. Lueje:** Writing – original draft, Investigation, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.agee.2024.108969.

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