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Vespa velutina: a menace for Western Iberian fruit production

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ABSTRACT

The Asian Hornet (*Vespa velutina*) is an invasive species that causes severely negative impacts on the ecosystems' functioning, human health and agriculture. Its impact extends to the detriment of orchards and vineyards as the species feeds on fruits to obtain sugar, consequently diminishing the marketable yield and reducing the overall quantity of final products. The survey presented in this manuscript aimed to study the agricultural technicians' appraisal of fruit damage caused by *V. velutina* since its appearance in the western coast of the Iberian Peninsula. In Galicia, Spain, 83% of technicians reported incidents on fruit damage, primarily affecting grapes, but also on pears and apples. In Portugal, 25% of technicians reported similar occurrences covering 8 species of fruit, notably on grapes, but also on apples, pears, figs, plums, peaches, blueberries and blackberries. This outcome showcases how *V. velutina* may cause non-negligible, direct detriment to fruit production, particularly to grapes. More studies are needed to quantify the economic impact of this type of damage.

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1. Introduction

The Asian Hornet, *Vespa velutina* Lepeletier 1836 (Hymenoptera: Vespidae), is a recently registered invasive species in Europe raising high ecological and economic concerns (Sundseth et al., 2016). The species was first observed in France in 2004, having after that and quickly spread to other European countries (Arca et al., 2015; Goldarazena et al., 2015; Granato et al., 2019; Monceau et al., 2014; Quaresma et al., 2022). In the western Iberian Peninsula, *V. velutina* was first registered in the north of Spain, in the Basque Country, in 2010 (Rojas-Nossa et al., 2021). Since then it has been spreading, having appeared in the North of Portugal in 2011 (Grosso-Silva & Maia, 2012) and in Galicia in 2012 (Diéguez-Antón et al., 2022a). The social life, high dispersal capacity and high fecundity of the queens contribute to the high population growth rate and quick spread of *V. velutina* populations (Cappa et al., 2019; Cini et al., 2018; Gabín-García et al., 2021; Monceau et al., 2015; Poidatz et al., 2018). As a generalist predator, *V. velutina* can hinders beekeeping and pollination services. On the one hand, *V. velutina* seeks proteins by hunting preferably bees but also other arthropods, such as flies and a wide spectrum of social wasps (Cappa et al., 2019; Cini et al., 2018; Rome et al., 2021). As a result, *V. velutina* leads to biodiversity losses in native insect fauna with a particular incidence on the communities of pollinators (Rojas-Nossa & Calviño-Cancela, 2020). On the other hand, this wasp, like other wasp species, also consumes carbohydrates sourced from floral nectar, sap, honeydew and fruits, which are essential for the survival of adult stages, the founder queens, workers, and males (Cappa et al., 2019; Monceau et al., 2014). However, there is limited research on the direct damage caused by *V. velutina* on fruit production. Fruit damage is expected to lead to reduced yields, increased labor and food costs, as well as higher

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investments in control methods. Studies have primarily focused on the impact of *V. velutina* on pollination reduction Monceau et al., 2018; Rojas-Nossa & Calviño-Cancela, 2020; Rojas-Nossa et al., 2023).

The initial reports of direct damages to fruits and grapes in Europe by *V. velutina* were documented by French farmers (Polleniz, 2007). Initial observations regarding fruit feeding activity in France by *V. velutina* date back to 2005 reporting on *Diospyros kaki* (Haxaire et al., 2006; Villemant et al., 2006). Since then, there have been ongoing reports documenting feeding activity on fruit (Monceau et al., 2014). However, up to the present date, no systematic monitoring has been conducted.

The diversity of sugar-rich fruits, such as in vineyards, fruit orchards, and berry plantations represent valuable food sources for *V. velutina* colonies (Fournier et al., 2017). As a result, agricultural areas with their diverse and complex land-cover patterns and a wide variety of fruit crops are highly attractive for the establishment of *V. velutina*. These areas, especially in the northeast of the Iberian Peninsula, are frequently composed of small-sized fields associated with agroforestry units (suitable for providing nesting support and wood fibers for nest construction).

The Iberian Peninsula has an ideal climate for the production of a wide variety of fruit. In Portugal, the area dedicated to fruit crops occupies around 700 thousand hectares (INE, 2022) where fresh and dried fruits, currently correspond, to a production of more than 126 thousand tons with an increasing trend (GPP, 2023).

Concerningly, *V. velutina* has established its colonies in agricultural areas with a high demand for insect pollinators, particularly in regions cultivating 'temporary irrigated crops', 'fruit crops' and 'nut crops' (Verdasca, 2021). Portugal has also around 190 thousand hectares of vineyards, mainly dedicated to the production of wine and of table grapes (IVV, 2023). Spain is one of the main fruit producers in the European Union, representing 32.9% of total EU fruit production (GPP, 2023). In 2022, Spain was the third largest wine producer in the world, representing 80% of the EU's wine production. In Galicia, the wine sector is one of the most important within the agrarian economy (Calvo et al., 2021).

Despite its relevance, there is a lack of data on the direct impact of *V. velutina* in the fruit sector. Given the absence of comprehensive knowledge and the recognized significance of this information, technicians in the fruit sector consider themselves a key audience. Their role as reliable sources stems from their training, technical expertise, and close involvement with the production chain at all stages. However, to the extent of our knowledge, there has been no previous research conducted on the awareness of agricultural technicians of the impact of *V. velutina* in the fruit sector.

To fill this gap in our knowledge, we conducted an exploratory survey among agricultural technicians. The survey aimed to assess their experience and knowledge regarding the impact of *V. velutina* on both fruit and wine production. In Portugal, since 2011, all technicians are regularly trained by the National Plant Protection Organization to identify *V. velutina*. Notably, all technicians have entomological courses as part of their graduation degrees. In addition to this, there is an ongoing national campaign to inform all stakeholders (agricultural technicians, workers and citizens), and technicians in particular, about *V. velutina* and how to distinguish it from other wasps (the following link shows an example of the training material used in this campaign: https://www.icnf.pt/api/file/doc/3d8ab53c92715e29). Furthermore, there is a website of citizen's science in which all citizens are encouraged to report the presence of *V. velutina* (https://stopvespa.icnf.pt/). In this regard, records show the very high accuracy levels of the citizens' reports of *V. velutina,* which is associated with the ease of distinguishing *V. velutina* from native wasps. Likewise, agricultural technicians in Spain are adequately trained and capable of correctly identifying *V. velutina*. Spain also follows and executes training programs designed for agricultural technicians to ensure their proficient identification of *V. velutina*.

The survey presented in this manuscript aimed to study the agricultural technicians' appraisal of fruit damage caused by *V. velutina* since its appearance in the western coast of the Iberian Peninsula. The survey in Galicia (Spain), primarily focused on the wine sector given the prevalence of vineyards in this region. In Portugal, the survey covered the entire mainland territory and focused on all fruit sectors. With this work we aim to provide insights on the significance of direct fruit damage caused by *V. velutina* in the fruit production industry.

2. Methods

2.1. Sample population

The survey was conducted online and anonymously, targeting agricultural technicians specialized in the fruit sector, directly engaged with fruit producers in several or all phases of the production circuit.

The survey was made available to agricultural technicians through sector-specific entities such as: agricultural warning stations, fruit and viticulture associations and cooperatives, and beekeeping associations. A list of entities was produced and subsequently, an email was sent to each of these entities (Table S1), providing them with instructions and a link to access the survey. The email also included a request for survey responses, specifically targeting agricultural technicians affiliated with these institutions. In Portugal, the technicians were from all over the continental territory (NUT II) (Figure 1a) working at: (1) agricultural warning stations; (2) fruit and viticulture associations or cooperatives; and (3) beekeeping associations. In Galicia, the surveyed population included technicians from the four Galician provinces working in the wine sector, and covered all existing protected designations of origin and geographical indications for wine production in Galicia (Figure 1a).

2.2. Development of the survey

An online survey (Table 1) was prepared using the Survey123 for ArcGIS application (https://survey123.arcgis.com/), and was made available in 2022, between June and September. The survey was structured into four sections: (1) technicians' profile; (2) technicians' awareness of *V. velutina* presence; (3) technicians' knowledge of fruit damage; and (4) open question about aspects to report not included in the previous questions.

After enquiring about the year in which the hornet arrived in the region (Section 1), the survey proceeded with inquiries specific to each subsequent year following arrival. Thus, respondents were requested to provide answers for each individual year.

On (Section 3) of the survey, technicians were asked to only report direct observation of fruit damage by *V. velutina*, thus excluding damage by other wasps for each year. Technicians were also asked to estimate the damage per percentage of fruits. The

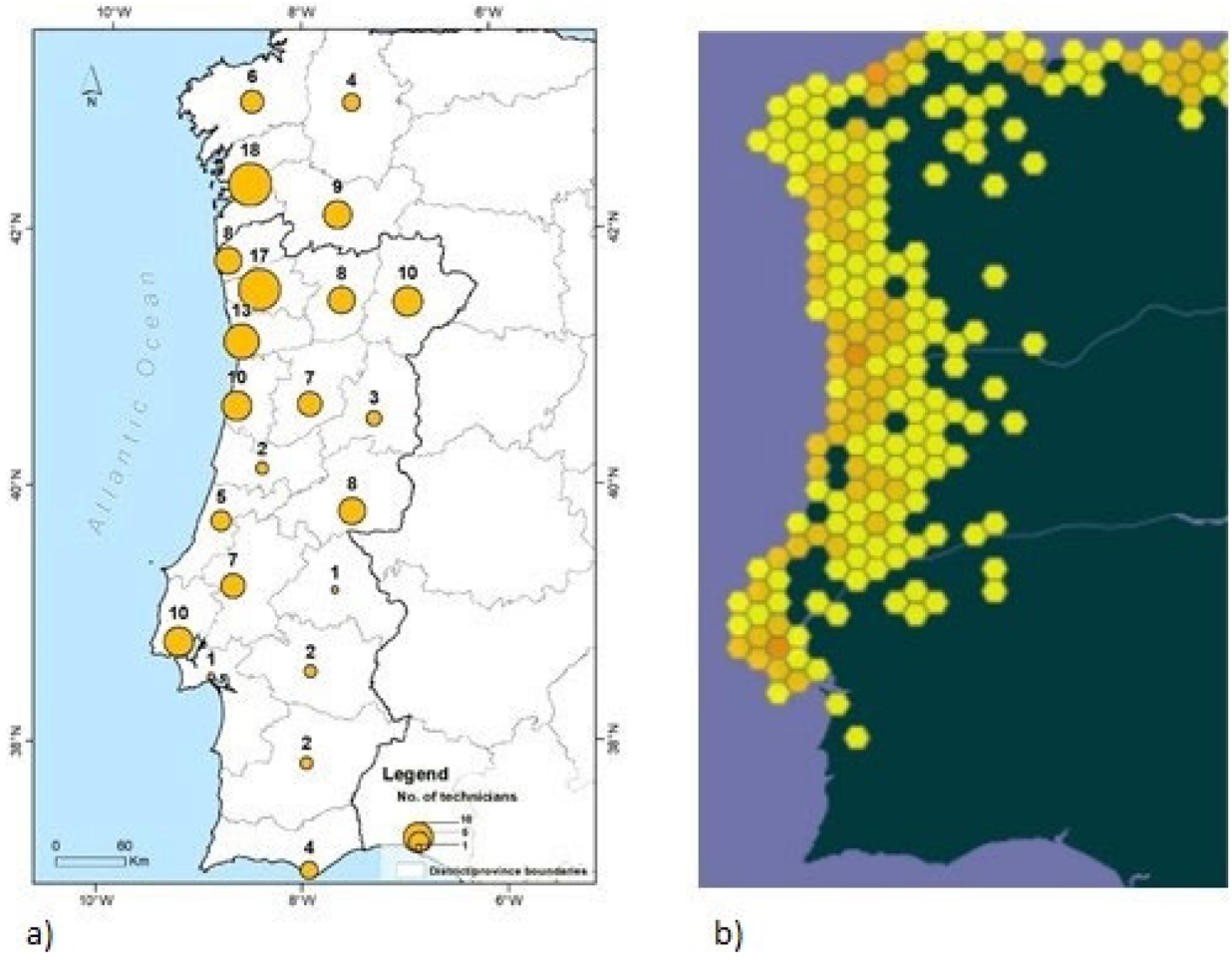

Figure 1. Work areas of technicians who responded to the survey 'Impact of *Vespa velutina* on fruit and viticulture', in the western coast of the Iberian Peninsula, mainland Portugal and Galicia region (Spain) (a) and distribution of *Vespa velutina nigrithorax* in 2023 (GBIF, 2023) (b).

Table 1. Survey items.

Sections	Item	Options
(1) Technicians profile	Gender	Male
		Female
	Age	20–40
		41–60
		61–80
	Years in profession	≤05
		6–10
		11–20
		21–30
		>30
	Agricultural professional category	Agricultural warning station
		Fruit growing
		Beekeeping associations
		Other
	Work areas (district in Portugal or province in Galicia)	Open question
(2) Awareness of *V. velutina* presence	*V. velutina* at the working area	Yes
		No
		Do not know
	In what year did it arrive (possibility of response as of 2012)	Open question
	Knowledge of nest destruction	Yes
		No
		Do not know
(3) Appraisal of fruit damage	Fruit damage	Yes
		No
		Do not know
	Which fruits were damaged	Open question
	At what stage of fruit development	Pre-maturation
		Maturation
		Ripening
	Describe the damage	Open question
	Were the fruits marketed	Yes
		No
		Do not know
	Fruit damage (%)	≤05
		6–25
		26–50
		51–75
		>75
	What time of year did occur	Spring
		Summer
		Fall
		Winter
(4) Aspects to report not included in the previous questions		Open question

proportion of damaged fruits results from this direct observation of the fruits. The survey allowed closed answers, though selection within a pre-established range of values, as well as open answers with no limit on the number of characters allowed. The open answers were presented by the technicians and were grouped according the typologies that were considered the most appropriate. The development and implementation of this survey complied with the European Union General Data Protection Regulation (EU, 2016) as data subjects were informed of the purpose of this survey and have given consent for the treatment of their personal data for the said purpose.

2.3. Data analysis

To ensure a higher rigor of the analysis to help future geographically-specific research and because surveyed stakeholders were not the same for both regions, answers to the survey were analyzed separately for Portugal and Galicia. Absolute and relative frequencies were estimated. Differences in frequencies according to personal data (e.g. gender, age, and working experience) and years were evaluated with Chi^2 test or Fisher exact test if one cell had a value of less than five. A *p*-value less than 0.05 was considered statistically significant. Data was analyzed using IBM SPSS version 26 (IBM Corp. Released, 2021).

3. Results

3.1. Technicians profile

A total of 123 technicians answered the survey, 25 in Galicia and 98 in Portugal. In both cases, the majority of technicians were male, 88% and 62%, for Galicia and Portugal, respectively. The predominant age group among technicians fell within 41 to 60 year, comprising 72% in Galicia and 67% in Portugal. Senior technicians, aged over 61 years, accounted for 20% in Galicia and 14% in Portugal. Technicians between 21 and 40 years represented 8% in Galicia and 17% in Portugal. The majority of technicians possessed more than eleven years of professional experience in fruit production, with 92% in Galicia and 62% in Portugal. In Galicia, the remainder 8% of the technicians had between 6 to 10 years of experience. In Portugal, the remainder 15% had between 6 and 10 years, and 21% had less than 5 years. Additionally, all technicians in Galicia were exclusively employed in the wine sector, with some individuals working across multiple provinces. In Portugal, technicians were employed in associations and cooperatives of fruit/viticulture (41%), agricultural warning stations (17%), beekeeping services (17%) and 25% with other types of agricultural services. The technicians' geographical area of work covered the 18 districts of mainland Portugal (Figure 1a) and some individuals worked in more than one district.

3.2. Awareness of V. velutina presence

During the survey period, *V. velutina* was found throughout the whole region of Galicia (Figure 1b) having expanded its presence between 2012 and

2019. By 2019, this invasive species was registered in all the surveyed areas. All the technicians in Galicia were well-informed about the presence of *V. velutina* within their region, and 89% of these professionals reported the destruction of *V. velutina* nests in their respective areas of work.

The situation in Portugal differs (Figure 1b). Since the invasion process occurred from north to south, most, but not all, regions had been invaded by *V. velutina* during the survey period (STOPvespa, 2023). Around 89% of the Portuguese technicians stated that *V. velutina* was present in their work area, whereas 3% mentioned that it was not and 8% did not know. Additionally, 87% of the technicians knew that *V. velutina* nests had been destroyed in their areas of work. After comparing the percentage of technicians who reported the presence of *V. velutina* in their work areas with the official records of confirmed *V. velutina* presence, it was possible to infer that approximately 86% of the technicians were well informed (Table 2).

3.3. Fruit damage appraisal

In Galicia, 83% of the technicians report damage caused to fruits. A minority (17%) was not informed about such damage. Most fruit damage reports referred to grapes *Vitis vinifera* L. (89% of responses) but other damaged fruits also reported, including pears *Pyrus communis* L. and apples *Malus domestica* Borkh (Figure 2).

The fruits were reported to be damaged mainly during the ripening and harvesting phase (96%). Concerning the percentage of the fruit damage, obtained from the observations within the indicated classes in the period shown, most responses (44%) referred to less than 5%, 25% indicated damage between 6% and 25%, 19% indicated damage between 26% and 50%, and 12% of the technicians reported more than 75% of damages (Figure 3).

The awareness of the occurrence of fruit damage showed no dependency on gender ($\chi^2 = 1.33$, p-value = 0.25), nor on the technicians' age ($\chi^2 = 1.19$, p-value = 0.55) or the number of years of working experience ($\chi^2 = 0.91$, p-value = 1.00).

In Portugal, only 25% of the technicians reported fruit damage, while 40% indicated no damages and the remaining 35% were unaware of such incidences. The technicians mentioned damage on eight different types of fruit, i.e. the three reported in Galicia, and also figs, *Ficus carica*, plums, *Prunus domestica* L., peaches, *Prunus persica* (L.) Batsch, blueberries, *Vaccinium myrtillus,* and blackberries, *Rubus fruticosus* (altogether including four botanical families, Vitaceae, Rosaceae, Moraceae and Ericaceae). Among these fruits, grapes were the most commonly mentioned (42.5%), followed by apples (20%), pears (10%), figs (10%), plums (10%), peaches (2.5%), blueberries (2.5%), and blackberries (2.5%) (Figure 2).

The fruits were predominantly damaged during the ripening phase, with 63% of the instances occurring at this stage. Additionally, 33% of the damage were observed during the maturation phase, while only 4% were reported in pre-maturation stage. Regarding the number of damages per percentage of fruits, the majority of responses (67%) referred to

Table 2. Awareness of *V. velutina* presence or absence by all the technicians.

V. velutina in the region	Response		
	Yes	No	Do not know
Portugal			
Present (92)	84	3	5
Absent (6)	3	0	3
Galicia			
Present (25)	25	0	0

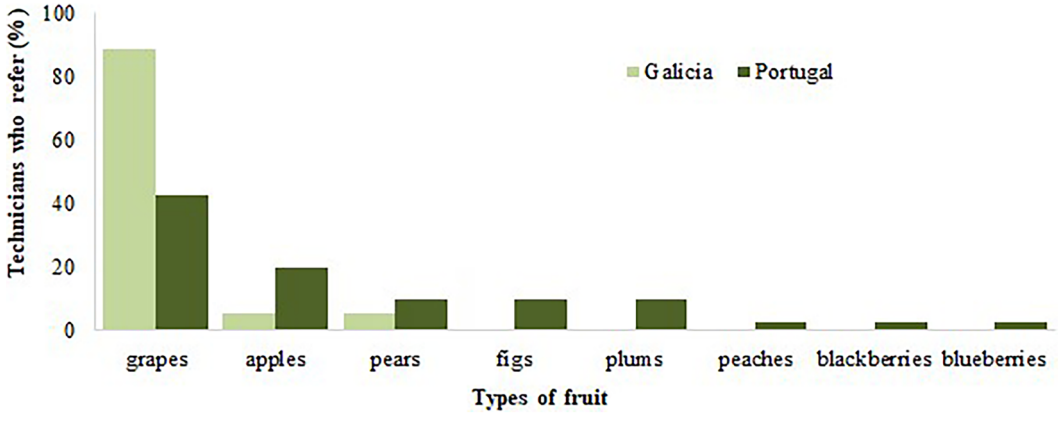

Figure 2. Percentage of fruit types reported damaged by the technicians.

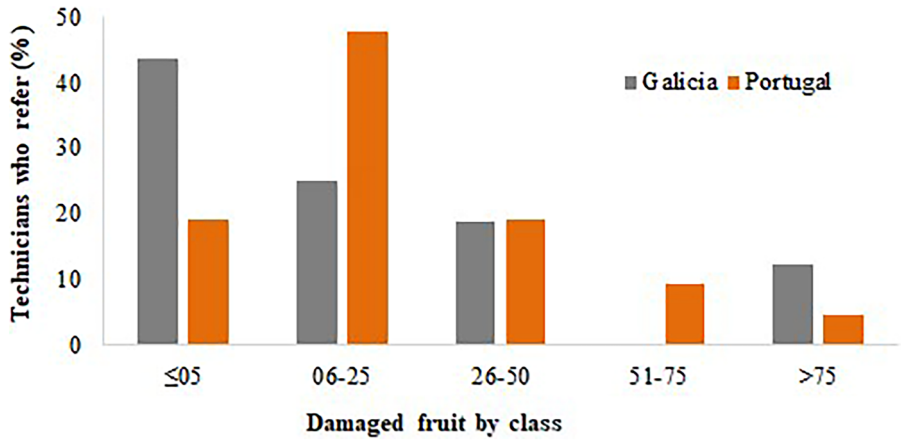

Figure 3. Damage per class fruits in percentage, reported by the technicians.

Figure 4. *Vespa velutina* eating table grapes and apple.

less than 25%. In addition, 19% of the reports indicated damage on 26 to 50 fruits, while 10% suggested damage on 51 to 75 fruits. A smaller proportion of technicians (5%) reported damage on more than 75 fruits (Figure 3).

The indication of the levels of fruit damage did not depend neither on the technicians' gender (χ^2 = 0.3361, *p*-value = 0.56), age (χ^2 = 0.0796, *p*-value= 0.96) nor the number of years of working experience (χ^2 = 5.1071, *p*-value = 0.28).

In both Galicia and Portugal, the ratio of technicians reporting damage (Figure 4) in a given year increased over time, following the first appearance and spread of *V. velutina* in these regions.

In Galicia, observations of damage on fruit were almost zero until 2016. After that, there was a continuous increase of reports, reaching 80% in 2021. In Portugal, the ratio of technicians who reported damage was almost zero until 2020 but, just one year later, there was a high increase in reports amounting to 80% in 2021. Similarly, the technicians' awareness in Portugal of fruit damage increased from 2020 to 2021 (Fisher exact test statistic = 0.0154, *p*-value < 0.05) (Figure 5).

3.4. Additional aspects of the survey, not included in the previous questions

In terms of aspects not covered in the previous sections and questions presented as an open-ended response, the provided answers were grouped into four categories (Table 3): (1) fruit damage, (2) hive attacks, (3) stings with people, and (4) control and surveillance. In both Portugal and Galicia, the main concern was related to fruit damage, in particular to the typology and severity of fruit injuries, and stings with farmworkers related with the difficulty in harvesting due to the high-levels of presence of *V.*

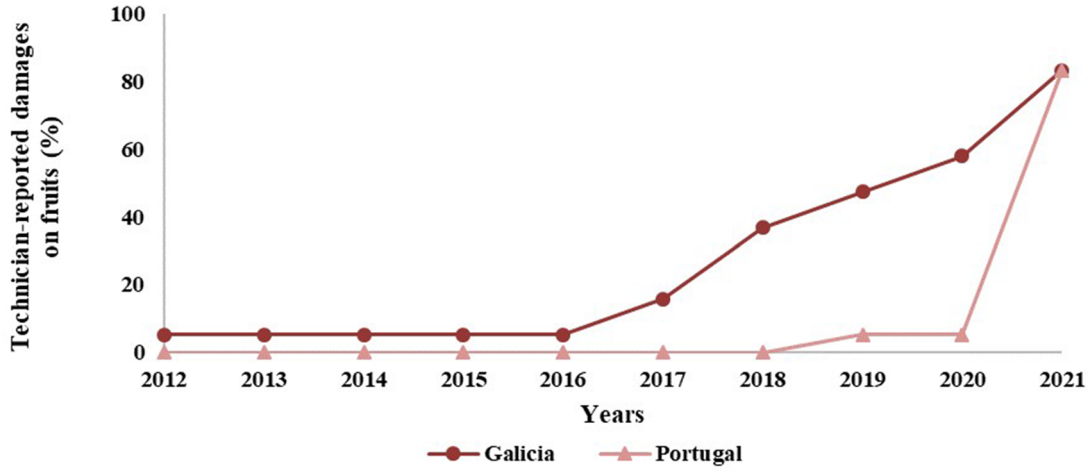

Figure 5. Percentage of technician-reported damage on fruits as a function of time.

Table 3. Major concern questions, expressed by the technicians in the open questions.

Major concern questions\categories	(1) Fruit damage	(2) Hive attacks	(3) Stings in people	(4) Control and surveillance
Stings with farmworkers			4	
Beekeepers stung next to hives			1	
Need for monitoring and combating traps				2
More information for monitoring				1
Sightings without knowing how to quantify the damage	1			
Strong attacks on hives with destruction		3		
Typology and severity of fruit injuries	9			
What is considered an attack?			1	
Portugal total	10	3	6	3
Difficulty in harvesting due to a lot of Asian Hornet activity			3	
Increased severity over time	1			
Study more effective traps model				2
Need for effective countermeasures				1
Typology and severity of fruit injuries	20			
Galicia total	21	0	3	3
Western Iberian total	31	3	9	6

velutina. In Galicia, there were reports of fruit damage and berry perforation in grapes, which contributed to the proliferation of other enemies, such as vinegar flies and rot.

4. Discussion

In this manuscript, we address a key research gap—the impact of *V. velutina* on of fruit damage - taking as a case study the western coast of the Iberian Peninsula, a European area invaded by *V. velutina*. We conducted surveys with agricultural technicians working in the fruit sector in this region with the goal to measure the technicians' knowledge of the extent of damage caused by this invasive species on fruit production. The research of this study can and should be expanded to other regions in Europe, where *V. velutina* is present and where fruit production is essential to sustain a balanced ecosystem, including France, Italy, Croatia, and Belgium. The extension of this study to other regions in Europe would consolidate knowledge on the damage of *V. velutina* on fruit production and strengthen control strategies.

The negative impacts associated with *V. velutina*, as described in the literature, have mainly related to its predatory activity on other insects, especially on pollinating hymenoptera, disrupting the latter's ecological function and causing biodiversity loss (Monceau et al., 2014; O'Shea-Wheller et al., 2023; Rojas-Nossa & Calviño-Cancela, 2020; Rojas-Nossa et al., 2023; Rome et al., 2021). Similarly, the most studied economic impacts for this invasive species focus on its impact on bee colonies, negatively interfering in the beekeeping activity (Diéguez-Antón et al., 2022b; Leza et al., 2019; Rojas-Nossa et al., 2022; Tan et al., 2007). These activities have indirect effects such as disrupting the pollination services of

crops, which in turn impacts yields and ultimately hinders the fruit production (Klein et al., 2006). Nevertheless, in addition to these risks, *V. velutina* may directly impact fruits during the ripening period, similar to the behaviour observed in other wasp species (Cranshaw et al., 2011; Pusceddu et al., 2022; Spradbery & Dvorak, 2022; Thomas, 1960). This consumption can lead to an additional detrimental effect on fruit production. For instance, Spradbery and Dvorak (2022) quantified the impact on Vvineyards caused by *Vespula* wasps and concluded that vineyards can experience a loss of up to half of their crops. Cranshaw et al. (2011) quantify the impact of *Polistes dominula* (Christ) (Hymenoptera: Vespidae) as being significant, reaching a level where cherry harvesting is abandoned due to severe injuries caused by chewing lesions.

Moreover, social wasps, while feeding on fruits, can potentially contribute to disease transmission and the spread of rot, leading to the decomposition of fruits (Madden et al., 2017). The direct fruit damage caused by *V. velutina* has been briefly problematized (Fedele et al., 2019; Van Itterbeeck et al., 2021) but, to the best of our knowledge, it has not yet been the main focus of research so far. On the other hand, the microbiome and mycobiome of *V. velutina* have been investigated (Cini et al., 2020; Pang et al., 2023) in both the native and invasive range and differences in yeast strains in relation to native vespids that act as yeast reservoirs and vectors may further impact wine production. Considering possible contaminations, it is important to implement good cultural practices.

The feeding activity on fruits by *V. velutina* was primarily observed during the summer coinciding with the maturation and ripening stages as noted on other social wasp species (Barbosa et al., 2014). Given the aggressive behaviour of this wasp species (Feás et al., 2021), its presence during the harvesting period also poses a risk for the workers, necessitating special attention by farmers and technicians.

The high awareness of technicians about the presence of *V. velutina* (89% and 83%, respectively, in Galicia and Portugal) contrasts with other invasive species for which the awareness is much lower. For example, Green et al., reported that only 58% technicians were aware of the respective tree pest or pathogens (Green et al., 2023). But the awareness depended on the species traits and its impact. In the case of *V. velutina,* its high visibility it has been given across all media and with its accentuated impact on public health and safety, all potentially contribute to the high awareness rates reported herein.

Several types of fruit were reported as damaged, but both in Portugal and Galicia, damages were primarily reported on grapes followed by apples and pears. While this response was expected in Galicia where participating technicians were from the wine sector, in Portugal, it is worth highlighting that, despite the different agricultural backgrounds of participating technicians, grapes were also the most mentioned fruit category. Due to the importance of the wine sector on these two regions (Neves et al., 2022), this impact may be non-negligible. Cultures with high demand for pollinators, such as temporary irrigated crops or fruit crops, are also arguably more susceptible to damages caused by *V. velutina*. Therefore, it is expected than in a near future the impact on fruit production may become even more prevalent (Verdasca, 2021), unless measures are taken to stop the spread of *V. velutina*.

We conclude that the surveyed technicians had high awareness levels of the presence of this wasp hornet (near 90% of technicians were aware of its presence). Moreover, concerning the fruit damage inflicted by *V. velutina*, is noteworthy to observe the escalating number of reports documenting observations of fruit damage over time since the invasion in both regions. These reports show that, while in 2012 only 5% of the respondents reported damage observations, reports drastically increased to over 80% in 2021. These figures demonstrate a growing number of observations of the adverse impact of *V. velutina* on fruit production, in line with an increase of the hornet's population, also in the areas under analysis (Lima et al., 2022).

Further research is required, for example with experimental studies, to determine the direct damage on fruit yields and economic impact caused by *V. velutina* on different fruit species.

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Author contributions

Conceptualization, N.A. and G.J.; methodology, N.A., G.J. and G.A; software, F.J.; formal analysis, N.A., F.J., G.A. and G.M.; research, N.A., G.A. and G.M.; resources, N.A., F.J., G.A. and G.M.; data analysis, N.A. and B.M.; writing—original draft preparation, A.N. and B.M; writing—review and editing, N.A., G.J., G.A., G.M. and B.M.; visualization, N.A., G.J., F.J., G.A., G.M. and B.M.; funding G.J and G.A. All authors have read and agreed to the published version of the manuscript.

Disclosure statement

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Data availability statement

All available data are incorporated in tables and figures within the manuscript. The datasets that were generated and/or analyzed during the current study are available from the corresponding author upon request.

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