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Effectiveness of sex pheromone traps in the integrated management of *Planococcus ficus* Signoret (Hemiptera: Pseudococcidae) in vineyards

Eficacia de trampas con feromonas sexuales en el manejo integrado de *Planococcus ficus* Signoret (Hemiptera: Pseudococcidae) en viñedos

Eficácia de armadilhas com feromônios sexuais no manejo integrado de Planococcus ficus Signoret (Hemiptera: Pseudococcidae) em vinhedos

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Rev. Fac. Agron. (LUZ). 2026, 43(1): e264304
ISSN 2477-9407
DOI: https://doi.org/10.47280/RevFacAgron(LUZ).v43.n1.IV

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Crop production
Associate editor: Dra. Evelyn Pérez Pérez
University of Zulia, Faculty of Agronomy
Bolivarian Republic of Venezuela

Received: 11-07-2025
Accepted: 12-11-2025
Published: 28-12-2025

Keywords:
Vine mealybug
Sustainable viticulture
Mass trapping

Abstract

Planococcus ficus Signoret (Hemiptera) represents an economically significant pest in viticulture, requiring timely, innovative, and effective control measures. While the application of sex pheromones in vineyards has primarily focused on mating disruption, there is a lack of studies evaluating their use in mass trapping as a management tool for this pest. This study was conducted in a commercial vineyard of the Crimson Seedless variety in Ica, Peru, and the objective was the efficacy of pheromone-baited traps (CINNAFIC®) deployed from postharvest 2020 through postharvest 2021. During this period, a trap density of 15 traps.ha^{-1} was maintained, resulting in the capture of 16,927 males, with a peak capture rate of 112.20 males.trap^{-1}.week^{-1} observed during the berry development stage. The greatest control was observed at harvest, with a 59.12 % reduction in the total mealybug population, highlighted by the production of infestation-free, fully exportable grape clusters, compared to 7 % infestation in control plots. Trap deployment limited mating opportunities, significantly altering the population structure by reducing nymphs and ovipositing females in treated plots. These results demonstrate that integrating pheromone traps with cultural practices and timely applications of pesticides and botanical extracts enables effective mealybug control without exclusive reliance on chemical insecticides. It is concluded that pheromone traps constitute a sustainable, effective, and viable tool for the integrated management of *P. ficus* in vineyards.

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Resumen

Planococcus ficus Signoret (Hemíptera) constituye una plaga de importancia económica en viticultura, su control demanda intervenciones oportunas, innovadoras y eficaces. Si bien el uso de feromonas sexuales en viñedos se ha centrado principalmente en la confusión sexual, no hay estudios que hayan evaluado su uso mediante trampas de captura como herramienta para manejar esta plaga. Este estudio realizado en un viñedo comercial de la variedad Crimson Seedless en Ica-Perú, tuvo por objetivo evaluar la eficacia de trampas con feromonas sexuales (CINNAFIC®) instaladas durante la etapa de poscosecha en el periodo 2020-2021. Se capturaron 16.927 individuos machos, con un pico de 112,20 machos.trampa^{-1}.semana^{-1} en la etapa de crecimiento de las bayas. El mayor control se observó en cosecha, con una disminución del 59,12 % en la población total de cochinillas, destacando la producción de racimos libres de infestación y completamente exportables frente al 7 % de racimos infestados en la parcela control. La instalación de trampas cebadas con feromonas limitó las posibilidades de apareamiento, lo que resultó en una alteración significativa de la estructura poblacional, con una reducción de ninfas y hembras con ovisacos en la parcela tratada. Estos resultados evidencian que el uso de trampas con feromonas, integrado a prácticas culturales, aplicaciones justificadas y oportunas de plaguicidas y extractos vegetales, permite un control efectivo de la cochinilla sin necesidad de recurrir al uso exclusivo de plaguicidas químicos. Las trampas cebadas con feromonas constituyen una herramienta sostenible, eficaz y viable para el manejo integrado de *P. ficus* en viñedos.

Palabras clave: cochinilla harinosa, viticultura sostenible, trampeo masivo.

Resumo

Planococcus ficus Signoret (Hemiptera) é uma praga de grande relevância econômica na viticultura, exigindo intervenções oportunas, inovadoras e eficazes para seu controle. Embora o uso de feromônios sexuais tenha se concentrado na confusão sexual, este estudo teve como objetivo avaliar a eficácia de armadilhas com feromônio sexual (CINNAFIC®) como ferramenta de controle. Conduzido em um vinhedo comercial da variedade Crimson Seedless em Ica, Peru (2020-2021); as 15 armadilhas de feromonas.ha^{-1}, capturaram 16.927 machos, com pico de 112,20 machos.armadilha^{-1}.semana^{-1} durante o desenvolvimento das bagas. A maior eficácia ocorreu na colheita, com redução de 59,12 % na população total de cochonilhas, e produção de cachos totalmente exportáveis, frente a 7 % de infestação na parcela controle. A limitação do acasalamento resultou em queda significativa de ninfas e fêmeas ovígeras na área tratada. Integradas a práticas culturais e aplicações pontuais de pesticidas e extratos vegetais, as armadilhas permitiram controle efetivo sem depender exclusivamente de inseticidas químicos. Conclui-se que as armadilhas com feromônio são uma alternativa sustentável e viável no manejo integrado de *P. ficus* em vinhedos.

Palavras-chave: cochonilha, viticultura sustentável, captura em massa.

Introduction

The mealybug *Planococcus ficus* Signoret (Hemiptera) is the main pest of *Vitis vinifera* L. (Vitaceae), affecting both the quality and yield of the crop; its mere presence on the bunches causes rejection for export (Castillo and Bello-Bedoy, 2022; Cocco *et al*., 2018). Conventional control is carried out with chemical pesticides (Pertot *et al*., 2017), however, their effectiveness has decreased due to the resistance acquired by the insect, its cryptic habits and its high fertility (Cocco *et al*., 2021). In addition, growing concern for human health and the environment has promoted integrated management of this cochineal, which includes other control methods, the rational application of pesticides, plant extracts, the release of natural enemies, and the use of sex pheromones (Pertot *et al*., 2017; Walton *et al.*, 2004).

The sex pheromone of *P. ficus*, identified as lavandulyl senecioate (Hinkens *et al*., 2001), has been used in diffusers in the mating disruption technique, demonstrating its effectiveness in vineyards in the United States, Italy, Tunisia, and Argentina (Cocco *et al*., 2014, 2018; Daane *et al*., 2020; Hogg *et al*., 2021; Lucchi *et al*., 2019; Mansour *et al*., 2017). It is postulated that factors such as high investment costs, large area requirements, labour and complexity of installation (between 247 and 840 dispensers per hectare are required) (Cocco *et al*., 2014; Hogg *et al*., 2021; Pertot *et al*., 2017) deter wine producers from using these products. Furthermore, the objective of this technique is to interrupt mating by confusing the male (Rizvi *et al*., 2021), without causing its direct death, which does not satisfy agricultural producers who prefer to see the death of the pest and prevent its persistence in the environment or migration to other fields or crops where it can reproduce.

Another way to use pheromones is through septa placed in adhesive traps that capture and eliminate males, interrupting the reproductive cycle with reduced doses of pheromone. This tool has been used successfully in the management of various agricultural pests in several crops (Kirk *et al*., 2021; Levi-Zada *et al*., 2018; Witzgall *et al*., 2010). In grapevines, the sex pheromone of *P. ficus* has been used exclusively for monitoring (Millar *et al*., 2002; Walton *et al*., 2004); however, there are no studies on its effectiveness as a direct control tool for this mealybug.

Therefore, the objective of this research is to evaluate the effectiveness of pheromone-baited traps as a tool in the integrated management of *P. ficus*, analysing the relationship between male captures and the total population of individuals, specifically first-stage nymphs and females with ovisacs. The aim is to generate information that will contribute to the adoption of pheromones in a more efficient and less polluting management of mealybugs in vineyards.

Materials and methods

The study was conducted during the 2020-2021 season in a Crimson Seedless vineyard in the town of Ica, Peru (75°42’0.00 “ S; 14°0’0.00” W, 535 m a.s.l), with a planting density of 1,600 plants.ha^{-1}, with a history of infestation by *P. ficus* (17.15 mealybugs.vine^{-1}.week^{-1}) prior to the study; whose phenological stages and environmental conditions are described in Table 1.

Table 1. Duration of the phenological stages of *Vitis vinifera* var. Crimson Seedless and average environmental conditions recorded in Ica, Peru, during the 2020-2021 season.

Phenological stage	Dates	Duration Weeks	Temp. (°C) (Min-Max)	RH (%) (Min-Max)
Post-harvest 2020 (POSC-20)	13/03 to 19/06/2020	15	22,65 (15,49-29,73)	64,6 (47,00-82,20)
Sprouting 2020 (BROT-20)	20/06 to 04/09/2020	11	19,22 (10,00-26,01)	58,27 (38,55-78,00)
Flowering 2020 (FLOR-20)	05/09 to 02/10/2020	4	19,43 (11,60 -27,20)	57,88 (38,75-77,00)
Berry Growth 2020 (CREC-20)	03/10 to 06/11/2020	5	20,12 (11,12-29,08)	57,70 (39,80-75,60)
Veraison 2020 (ENVE-20)	7/11 to 11/12/2020	5	22,08 (14,40-29,70)	57,00 (38,80-75,20)
Harvest 2020 (COSE-20)	12/12/2020 to 22/01/2021	6	24,08 (17,83-30,28)	59,25(44,50-74,00)
Post-harvest 21 (POSC-21)	23/01 to 12/03/2021	7	25,41 (18,47-32,33)	55,71(38,00-73,43)

Temp.: temperature, HR: relative humidity.

The vineyard management programme was developed in accordance with the principles of Integrated Pest Management (IPM) and included the application of chemical insecticides and biopesticides, the release of natural enemies and the implementation of standard cultural practices.

Installation of pheromone-baited traps

Two non-contiguous experimental plots were selected: one treated with pheromone traps (Pheromone Plot: PP) and one without treatment (Control Plot: CP). Fifteen delta traps were distributed in the PP, each equipped with a 400 cm² adhesive strip and a rubber septum impregnated with 0.015 g of lavandulyl senecionate (CINNAFIC®), replaced every two months according to the supplier's instructions.

Male captures

Individuals were recorded weekly under a Leica® stereoscope at the Klaus Raven Büller Entomology Museum, National Agrarian University of La Molina. The adhesive sheets were changed after each count, while the traps remained in place throughout the experimental period (Figure 1).

The two main arms and the trunk of 20 randomly selected vines in each plot (both in the PP and CP) were inspected weekly, recording the number of nymphs (I, II-III) and females (including those with ovisacs). The mealybugs were not removed from the plant and the vines evaluated varied in each sampling.

Monitoring of the mealybug population. Incidence of cochineals in clusters

At harvest, 32 vines (2 % of the plot) were randomly selected per plot; 10 clusters were harvested from each vine and evaluated for the presence or absence of *P. ficus* according to the phytosanitary protocol for export (Peruvian National Agricultural Health Service [SENASA], 2020). The incidence was calculated using equation 1 (Eq. 1).

$$\text{Incedence } \% = \frac{\text{Number of clusters with presence of } P.\ ficus}{\text{Total number of clusters}} \text{ X } 100 \quad \text{(Eq. 1)}$$

Design and statistical analysis

To evaluate the effectiveness of sex pheromone traps in controlling the *P. ficus* population, a completely randomised experimental design was implemented. The experimental unit corresponded to each trap installed in the vineyard. The presence or absence of sex pheromone traps was considered as treatment, which corresponded to the plot with *P. ficus* pheromone traps (PP) and the control plot without traps (CP).

The total population of mealybugs, first-stage nymphs, and females with ovisacs was recorded. The replicates corresponded to periodic sampling carried out at each phenological stage of the crop, totalling 53 weekly samples. The data were analysed using a one-way analysis of variance (ANOVA) to compare the populations between treatments

Figure 1. Layout of *Planococcus ficus* pheromone traps in the *Vitis vinifera* var. Crimson Seedless vineyard in Ica, Peru. a) Front view. b) Side view. c) Field sampling slide with *P. ficus* male population, prior to laboratory analysis.

using InfoStat v. 2020® software. Prior to analysis, the assumptions of normality were verified. When significant differences were detected ($p<0.05$), Tukey's test was applied for multiple comparison of means.

Results and discussion

Throughout the 2020-21 season, *P. ficus* (Figure 2) was observed in the vineyard, which is consistent with reports by Geiger *et al*. (2001) in the United States, Walton and Pringle (2003) in South Africa, and Becerra *et al*. (2006) in Argentina, who documented the persistence of this pest throughout the wine-growing season.

Capture of males

The study began in the 2020 post-harvest stage, at which point the sex pheromone traps proved highly effective, with a weekly average of 15.58 males.trap^{-1} and a maximum of 28.40 males.trap^{-1}, indicating a high population density of the insect in this phenological phase. Except during the sampling on 6 and 15 June 2020, when a marked decrease in catches was observed, attributable to the application of acetamiprid (6 June 2020) and the implementation of pruning (15 June 2020), the latter being a routine vineyard management practice. Both interventions contributed to a significant population reduction, with an average of 6.33 males.trap^{-1} recorded at the end of this stage (Figure 2). During the budding phase, male captures in pheromone traps showed a further increase, with an average of 11.61 males.trap^{-1} and a maximum value of 21.93 males.trap^{-1} (Figure 2). These results are consistent with those obtained by Mansour *et al*. (2017), who reported similar patterns of population increase during sprouting, and suggest a close relationship between the phenological development of the crop and the reproductive dynamics of *P. ficus*, reinforcing the importance of timely control at this critical stage of the crop cycle.

The highest catches were recorded during the flowering, berry growth and veraison stages (Figure 2), with weekly averages of 35.22, 86.89 and 23.80 males.trap^{-1}, and peak values of 83.07, 112.20 and 44.07 males.trap^{-1}, respectively. These values were also used to make decisions regarding the timing of phytosanitary product application and were based on the additional use of pheromones for population monitoring. Mansour *et al*. (2017) also reported high catches during flowering under similar conditions, although they observed considerably lower values at veraison, possibly due to higher temperatures than those recorded in the present study.

During the harvest and post-harvest phases, catches declined significantly, with weekly averages of 3.33 and 4.23 males.trap^{-1}, respectively. This result is particularly important, as it is not possible to apply plant protection products during harvest due to regulatory restrictions and the risk of residues in fruit intended for consumption. In contrast, Mansour *et al*. (2017) reported higher capture values at these same stages, even under comparable environmental conditions.

In total, 16,927 males were captured during the 2020-2021 campaign (Table 2); considering the fertility rate estimated by González-Luna and La Rossa (2016) -134.22 nymphs.female^{-1} under similar conditions-, and assuming the most conservative scenario (a single copulation per male), it is estimated that the installation of pheromone traps could have prevented a population of more than 2 million mealybugs.ha^{-1}. This projection highlights the potential of using sex pheromones not only as a monitoring tool, but also as a strategic component in the population suppression of *P. ficus* in commercial vineyards.

Mealybug density between plots-effect of pheromone traps

The total density of mealybugs (nymphs and females) was significantly lower in PP (20,326 individuals) compared to CP (27,954 individuals), representing a reduction of 27.29 % (Table 2). When analysing the period between bud break and harvest, the reduction in population density reached 32.63 %, in agreement with Mansour *et al*. (2017), who reported a 32.68 % decrease using pheromone dispensers during the same phenological stages in vines.

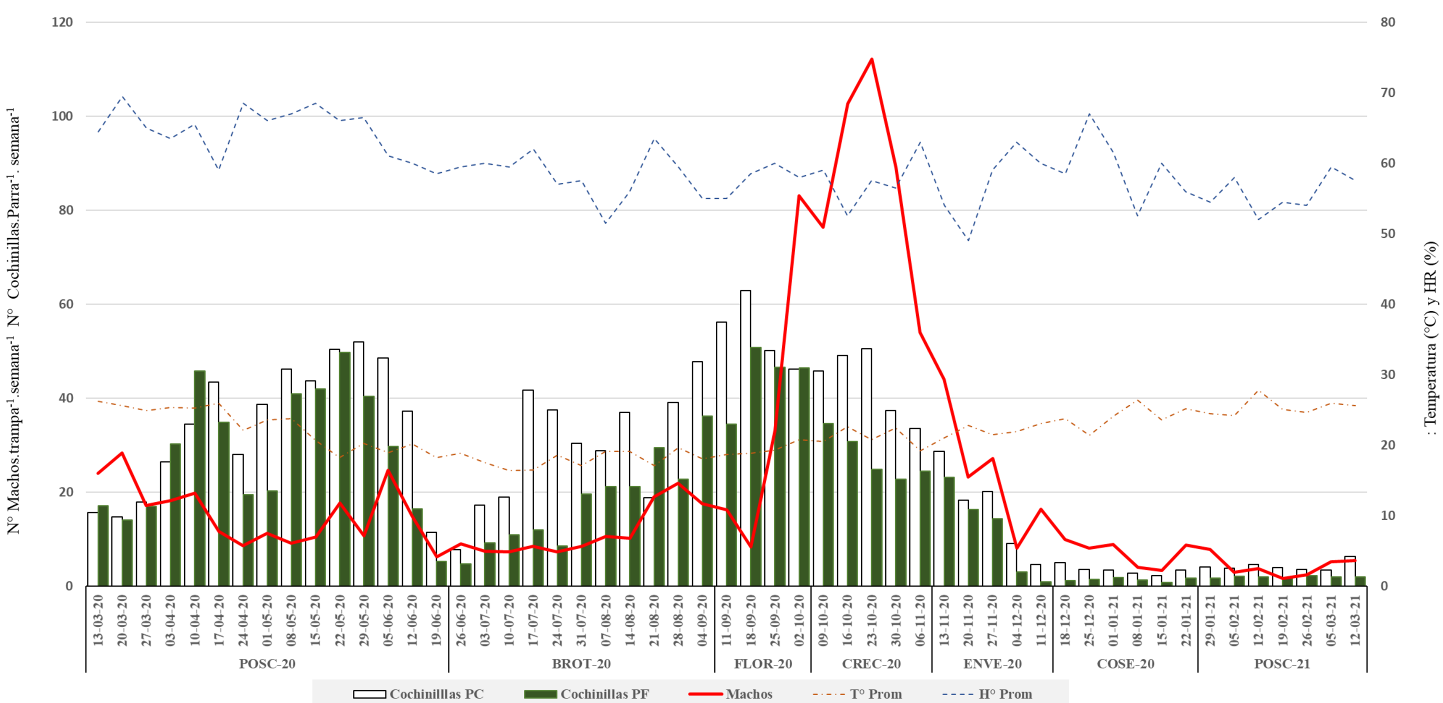

Figure 2. Average number of males captured in pheromone traps and density of mealybugs (females and nymphs) in the control plot (CP) and the plot treated with pheromones (TP), together with temperature (°C) and relative humidity (% RH) records during the 2020-2021 season, in a Crimson Seedless vineyard in Ica, Peru.

Table 2. Total males and averages of total mealybugs, nymph I and females with ovisacs per vine (± SSE) and totals recorded during the 2020-2021 season in a Crimson Seedless vineyard in Ica, Peru.

Stage	Total males	Total cochineals		% Control	Total cochineals		% Control	Females with ovisacks		% Control
		PC	PF		PC	PF		PC	PF	
POSH-20	3,506	33.94 (± 3.60)	28.25 (± 3.50)	16.76	15.31 (± 2.10)	12.40 (± 2,16)	18.97	3.78 (± 0.49)	2.95 (± 0.26)	21.80
SPRT-20	1,915	29.57 (± 3.74)	17.82 (± (2.92)	39.74*	9.05 (± 1.84)	5.41 (± 1,66)	40.18	2.57 (± 0.38)	1.29 (± 0.04)	49.82*
FLOW-20	2,113	53.84 (± 1.94)	44.60 (± 1.87)	17.16	26.16 (± 1.90)	21.29 (± 3.98)	18.63	2.01 (± 0.25)	0.61 (± 0.07)	69.57*
GROW-20	6,517	43.30 (± 3.34)	27.53 (± 2.22)	36.42**	21.51 (± 1.24)	6.53 (± 1.17)	69.64**	2.14 (± 0.38)	0.60 (± 0.18)	71.96**
VERIS-20	1,785	16.19 (± 4.25)	11.60 (± 4.17)	28.35*	7.86 (± 2.29)	2.00 (± 0.90)	74.55**	0.80 (± 0.20)	0.30 (± 0.06)	62.50*
HARVS-20	647	3.43 (± 0.37)	1.40 (± 0.14)	59.12**	1.27 (± 0.25)	0.36 (± 0.09)	71.71**	0.19 (± 0.05)	0.03 (± 0.01)	82.61**
POSH-21	444	4.29 (± 0.37)	2.01 (± 0.07)	53.00**	1.08 (± 0.20)	0.29 (± 0.04)	73.51**	0.31 (± 0.09)	0.05 (± 0.02)	83.72*
Total	16,927	27,954	20,326	27.29	11,916	7,551	36.63*	2,220	1,320	40.54*

*: Significative ($p<0.05$), **: Highly significant ($p<0.01$).

In all phenological stages evaluated in vines, the density of scale insects in the PP was lower than in the CP (Table 2); however, during the post-harvest phase of 2020, no significant differences were recorded, suggesting that pheromone traps failed to alter population dynamics in the PP, possibly due to the high infestation prior to the study. However, at the end of this period, as with the male population, the application of acetamiprid, combined with winter pruning, significantly reduced the density of *P. ficus* in both experimental plots (PP and CP). During budding, on the other hand, control with pheromone traps was significant (39.74 %), probably due to the previous population decline, which is consistent with Rizvi *et al*. (2021), who highlighted that the effectiveness of control with sex pheromones is much greater when initial populations are low. In addition to inducing budding, pruning contributed to pest management by removing foliage infested with scale insects. As highlighted by Walton and Pringle (2003), this practice, by thinning the canopy, favours the action of natural enemies and improves the effectiveness of phytosanitary applications.

During flowering, despite the application of spirotetramat (09/09/2020), the cochineal population increased in both plots, probably due to favourable environmental conditions and greater food availability; there were no significant differences between the plots and the control because the effect of the pheromone traps was limited (17.16 %). During berry growth and veraison, the differences between PP and CP were significant ($p<0.05$) to highly significant ($p<0.01$), respectively; the applications of citrus extract (30/10/2020) and cinnamon extract (27/11/2020), included in the integrated pest management (IPM) carried out by the producer, would have enhanced the effect of the pheromone traps, improving control. Lee *et al*. (2020) reported nearly 100 % mortality in adult female *P. citri* treated with plant extracts, including cinnamon.

During harvest, a critical stage for managing *P. ficus*, control in PP reached 60 %, with highly significant differences ($p<0.01$) compared to PC, supporting the use of sex pheromones as a key tool in light of restrictions on the use of chemical insecticides. In the 2021 post-harvest period, control remained at 53 % in PP, with a weekly average of only 2.01 mealybugs per vine, i.e. a 14-fold reduction compared to the start of the study, indicating that the next season will begin with a low population of this insect. These results support the implementation of a strategy of continuous pheromone use over several seasons to achieve greater control efficacy (Cocco *et al*., 2018; Sharon *et al*., 2016).

Effect on the population structure of nymph I and females with ovisacs

Significant differences were observed between plots; the PP recorded a lower abundance of nymphs I (7,551) compared to the PC (11,916), equivalent to a control of 36.63 % (Table 2). Similarly, Kamarudin *et al*. (2006) reported a lower percentage of *Metisa plana* Walker (Lepidoptera: Psychidae) nymphs in oil palm plots with pheromone traps (9.10 %) compared to the control plot (28.60 %).

In females with egg sacs, 1,320 were recorded in the PP compared to 2,220 in the CP, equivalent to a control of 40.54 % (Table 2). The highest levels of control occurred during harvest, suggesting that the sustained use of pheromone traps effectively reduces reproductive stages. These results coincide with Cocco *et al*. (2014), who also reported a lower proportion of nymphs and pre-ovipositing females in plots treated with pheromone dispensers. In both studies, significant variations in population composition were detected, highlighting a proportional reduction in reproductive stages; this effect is key to the integrated management of *P. ficus*, since fewer females with ovisacs implies lower reproductive potential and translates into lower infestation pressure in the next phenological cycle of *V. vinifera* (Figure 3).

Presence of *P. ficus* in *V. vinifera* bunches during harvest

During harvest, *P. ficus* was not detected in clusters harvested from the PP, while in the PC, 7 % of clusters were affected. This result differs from that reported by Cocco *et al*. (2014), who, although they observed significant control, recorded the presence of mealybugs in clusters from vineyards treated with pheromone dispensers. Complementarily, Kamarudin *et al*. (2006) reported a 22 % increase in the weight of *V. vinifera* clusters in oil palm plots with pheromone traps compared to 15 % in the control plot, attributing this effect to the reduction in mating and oviposition of the basket worm (*M. plana*), which resulted in lower populations and less damage to the crop.

Conclusions

The use of traps baited with sex pheromones in *V. vinifera* reduced *Planococcus ficus* populations, directly affecting the population structure and limiting the reproductive potential of the pest. This suggests that this tool has potential as a component of integrated management, especially when implemented early, after pruning and in combination with other cultural and phytosanitary practices.

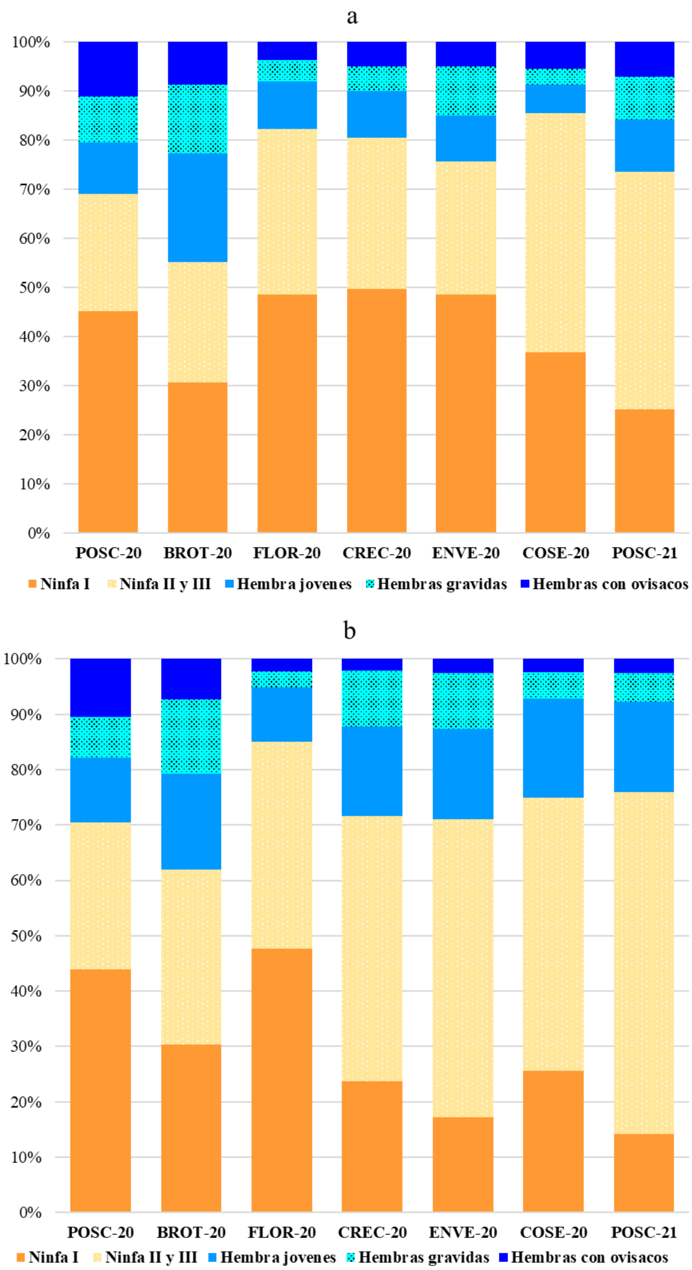

Figure 3. Population structure of Planococcus ficus mealybugs during the 2020–2021 season. A) Control plot; b) Plot with pheromone traps in a Crimson Seedless vineyard in Ica, Peru.

The absence of mealybugs in harvested *V. vinifera* clusters demonstrates that this tool is effective at stages when chemical insecticides cannot be applied, ensuring the safety and sanitary quality of grapefruit for export. It is also recommended that further studies be conducted to consider variations in pheromone density or the number and colour of traps, in order to expand knowledge about their effectiveness and thus optimize their implementation in integrated pest management programmes.

Acknowledgements

We would like to thank engineers Eveliz Ramos Yesquen, Cristofer Acuña Huaracc and Rosa Juan de Dios Landeo from the National Agrarian University of La Molina for their collaboration, and Cinnamon SAC for providing the traps and CINNAFIC® sex pheromones.

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