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Research article

Farmers' perceptions and knowledge of natural enemies as providers of biological control in cider apple orchards

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A R T I C L E I N F O

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A B S T R A C T

While the importance of biological control for crop production is widely acknowledged, research on how farmers perceive on-farm natural enemies remains scarce. This paper examines cider-apple farmers' perceptions and knowledge of the concept of biological control and the specific organisms underpinning its provision (i.e. natural enemies) in the cider-apple orchards of Asturias (N Spain). Although these orchards host a high diversity of natural enemies, certain pests continue to be a problem, e.g. the codling moth and the fossorial water vole. By conducting 90 face-to-face surveys, we found that farmers "under-estimated" the importance of biological control and the role played by natural enemies in suppressing pests from cider-apple orchards. Furthermore, farmers were particularly unaware of the indirect benefits of biological control, such as the increased quality and yield of product. Farmers also perceived that different taxa of natural enemies contribute to biological control to differing extents, for example, birds, such as buzzard, robin and tit, were perceived as the most important natural enemies, while arachnids and insects (excluding ladybug) were perceived as less important. This perceived difference in the biological control contribution of vertebrates and invertebrates could be influenced by farmers' local knowledge, acquired on-farm through daily experiences, as well as from external sources. In addition, we found that farmers did recognize many interactions between natural enemies and pests, although there were serious misconceptions and knowledge gaps. Finally, we revealed that education level, being a full-or part time farmer rather than a 'hobby' farmer, time spent working in agriculture, and orchard size are all factors that positively influence farmer's perception of natural enemies. Our results provide insights for a future management of cider-apple orchards which promotes biological control through: (1) creating initiatives to develop farmers' knowledge regarding biological control and natural enemies, (2) fostering traditional farming systems that contribute to preserving local ecological knowledge of biological control, and (3) establishing networks of farmers so they can learn from each other and share local knowledge.

1. Introduction

Crop production depends on several regulating ecosystem services, such as pollination (Garibaldi et al., 2011), biological control (Bommarco et al., 2013) and the maintenance of soil fertility (Zandbergen et al., 2017). However, despite their importance, these regulating services, in particular biological control, have been underexplored in ecosystem service research pertaining to agroecosystems (Nieto-Romero et al., 2014; Fagerholm et al., 2016). Biological control is understood as the reduction of one organism population by another one (Cock et al., 2010). Van Lenteren et al. (2018) described four types of biological control: natural, conservation, classical, and augmentative. In this paper, we focus on natural biological control (*hereafter* biological control) because this refers to those situations whereby naturally occurring beneficial organisms reduce the occurrence of pest organisms without any human intervention.

Biological control is an efficient, profitable and sustainable alternative to chemical means of pest control to reduce crop losses (Bale et al., 2007; Bommarco et al., 2013; Losey and Vaughan, 2006). At the farm-level, biological control not only reduces pest outbreaks, but also has a positive economic impact (Naranjo et al., 2015). In addition, it leads to other positive social-ecological outcomes, such as reducing

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human health risks (Sarwar, 2015) and conserving biodiversity (Boatman et al., 2007; Gibbs et al., 2009; Isenring, 2010). As such, biological control has been extensively promoted over the past decade, yet its farm-level adoption is slow and hampered by multiple factors (Hajek and Eilenberg, 2018). In fact, biological control is decreasing worldwide (MA, 2005; IPBES, 2018) because of the impact of several drivers, such as land-use change (Chaplin-Kramer et al., 2011; Rusch et al., 2016), climate change (Oliver et al., 2015) and the intensification of farming systems (Emmerson et al., 2016).

A wide range of organisms deliver ecological functions to provide biological control including insectivorous birds (García et al., 2018), bats (Puig-Montserrat et al., 2015), ladybugs (Jacobsen et al., 2019), spiders (Happe et al., 2019; Hong-xing et al., 2017), anthocorids (Jacobsen et al., 2016), nematodes (Nermuť et al., 2019), parasitoids (Hong-xing et al., 2017) and microorganisms (Van Lenteren et al., 2018). Increasing on-farm biodiversity of natural enemies is known to enhance biological control (Dainese et al., 2019; Gurr et al., 2003; Ives et al., 2000; Wilby and Thomas, 2002). For example, a greater richness and abundance of natural enemies ensures more mechanisms by which different prey are consumed across environments and over time (Letourneau et al., 2009; Tscharntke et al., 2005; Vance-Chalcraft et al., 2007). However, the uneven effectiveness of natural enemies for pest suppression does need to be taken into account (Greenstone et al., 2010; Loreau et al., 2001; Straub and Snyder, 2006). For example, the spined soldier bug (*Podisus maculiventris*) preys more on Colorado potato beetle (*Leptinotarsa decemlineata*) than other predators (Greenstone et al., 2010).

Although there is considerable ecological research on the organisms underpinning biological control (Chaplin-Kramer et al., 2011), little social research on perceptions of biological control and the organisms involved has been conducted (Rawluk and Saunders, 2019). Farmers' agro-ecological knowledge of biological control and their perceptions of the contribution on-farm biodiversity makes to pest control have, for example, been routinely overlooked. Most studies have, instead, focused on the motivation and attitude of farmers who adopt biological control measures (Abdollahzadeh et al., 2016; Goldberger and Lehrer, 2016). Others have focused more generally on the farmers' perceptions of pesticide use, insects as natural enemies (Wyckhuys et al., 2019), pests (Sekamatte and Okwakol, 2007; Van Mele et al., 2009) and pest management (Midega et al., 2016; Morales, 2002; Okonya and Kroschel, 2016).

Understanding farmers' perceptions of biological control can shed light on their motivation to apply, or not, farming practices that support natural enemies (Abdollahzadeh et al., 2016). In turn, this information impacts on any potential implementation of sustainable management practices and informs policy-makers about what is required to support and encourage farmers in the uptake of such practices (Savary et al., 2017). This is particularly relevant in the European context, where the Common Agriculture Policy (CAP) advocates agri-environment schemes through which farmers support biodiversity and biological control (Bengtsson et al., 2005; Van Buskirk and Willi, 2004).

The main objective of this paper is to examine farmers' perceptions and knowledge of the biodiversity underpinning biological control in cider-apple orchards in Asturias (N Spain), specifically: (1) the importance they consider biological control to have, for croplands in general as well as for their own orchards; (2) their ability to recognize various natural enemies and their knowledge of the degree to which each contributes to pest control in their own cider-apple orchards; and (3) their knowledge of the specific interactions between natural enemies and pests. In addition, (4) we assess whether there is a relationship between farmers' perceptions and knowledge of natural enemies as providers of biological control and, certain farming and socio-economic characteristics of the farmers themselves.

The remainder of the manuscript is organized as follows: The second section describes the characteristics of the cider-apple region in Asturias, including relevant pests and pest control practices commonly in use. Section three describes the data collection and analysis procedures. The results in relation to each aim of the research are in section four, while section five describes farmers' perceptions and knowledge about the importance of biological control, natural enemies and their interactions with pests and the farming and socio-economic characteristics behind these perceptions. Also in this section, we suggest ways to enhance farmers' understanding of the importance of natural enemies. The concluding section provides insights for the management of cider-apple orchards in order to promote biological control.

2. Overview of cider-apple orchards

The research was conducted in the cider-apple region of Asturias (N Spain) (Fig. 1), across six municipalities (Colunga, Nava, Sariego, Siero, Villaviciosa and the rural areas of Gijón). Asturias, with its extensive and semi-extensive orchards, is the most productive region of cider-apple (*Malus x domestica* Borkh) in Spain, the crop covering 4131 out of the total 8245 ha that comprise the region (INE, 2018). Orchards are relatively small, between 0.5 and 2.0 ha, surrounded by hedgerows and embedded in a traditional landscape mosaic of multiple land-uses (e.g. livestock pastures, eucalyptus plantations, natural forests): an optimal system for preserving beneficial animals for pollination and biological control (Miñarro and Prida, 2013; García et al., 2018).

The management of Asturian cider-apple orchards remains to a great extent traditional (Dapena and Fernández-Ceballos, 2007), although cultivars have been locally and historically selected to tolerate common apple diseases (scab, canker and powdery mildew) (Dapena and Blázquez, 2009). The most detrimental and economically important pests are the fossorial water vole (*Arvicola scherman*), which attacks the roots and may cause tree death (Somoano et al., 2017), and the codling moth (*Cydia pomonella*), which damages the fruit (Peisley et al., 2016). Other pests of note are the apple aphid (e.g. *Dysaphis plantaginea, Aphis* spp.), which harms young shoots (Miñarro et al., 2010), and the apple blossom weevil (*Anthonomus pomorum*), which damages blossom (Miñarro and García, 2018). Within the six municipalities selected, only 51% of farmers use pesticides, and this only when they consider it necessary, treatment generally consisting of spraying diflubenzuron against codling moth (*own data, not shown*).

Much pest control in Asturian cider-apple orchards, then, relies on natural enemies. Previous research has demonstrated the importance of birds (e.g. tits, thrushes, robin, woodpeckers) for biological control in the region (García et al., 2018), as well as the essential roles played by birds of prey (e.g. buzzard, owls), carnivorous mammals (e.g. mustelids), a wide variety of insects (e.g. ladybug, earwig, hoverflies) and arachnids (spiders) (Miñarro et al., 2011).

The Asturian region is sparsely populated. The six municipalities selected have a total rural population of 103,115 inhabitants, with an average population density of 4.1 inhabitants per hectare. Fifty-nine per cent of the population is aged between 25 and 65, 21.0% is over 65 and 20.0% below 25. The active population in the area is principally employed in service industries (12.9%), manufacturing and building (7.9%), tourism (3.8%) or agriculture (2.5%). Tourism related to cider-apple orchards, cider production and the cider culture and its gastronomy is becoming increasingly important economically (INE, 2018).

3. Materials and methods

3.1. Data collection

Between January and July 2018, we conducted 90 face-to-face surveys with cider-apple farmers over 18 years of age, randomly selected from across the 6 municipalities of the study area. The sample size is representative of the rural population in the region (see above) at the 95% level, with a sampling error < 10%. Surveys were carried out either in quiet public spaces or in farmers' own orchards. We pre-tested the

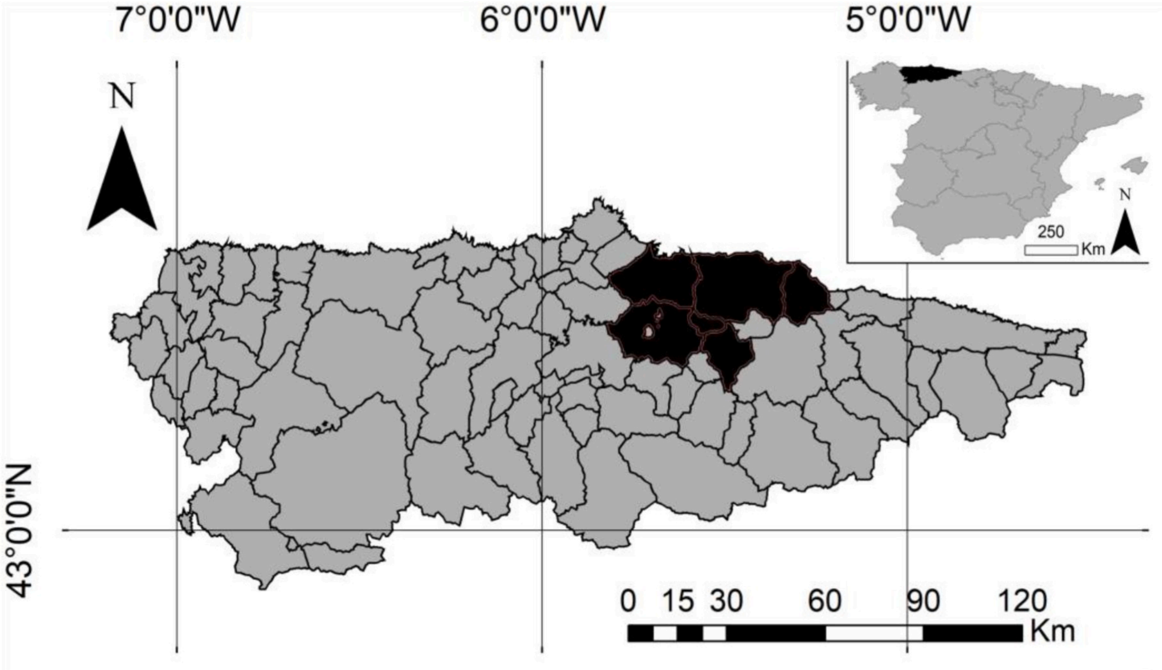

Fig. 1. Study area. Inset shows location within Spain of Asturias region. Larger image shows the municipalities of Asturias, with those selected within the cider-apple region for this study depicted in dark gray.

questionnaire with six other farmers ensure all questions were understood by respondents.

The final questionnaire had four sections, each linked to a specific aim of this research: (1) farmers' perceptions of the importance of biological control for croplands in general (*hereafter* croplands) and their own cider-apple orchard(s) specifically. This was based on a set of open and closed questions; (2) farmers' knowledge of organisms that act as natural enemies in cider-apple orchards. This was ascertained through farmers' responses to a table asking if they had ever sighted (at any time in the area), knew about (were aware through local hearsay, folk culture, information provided publically or on courses, or their own search for information) or recognized as a natural enemy 14 taxa, each of which was illustrated with an image of a representative species. Only ten of the taxa are known natural enemies in the area (García et al., 2018; Miñarro et al., 2011) (Table B1); (3) farmers' perceptions on the interactions between natural enemies and pests in cider-apple orchards, based on ratings of importance for the ten known local natural enemies, and on direct questions relating to which natural enemies controlled a list of local pests in cider-apple orchards; and (4) farming and socio-economic details of the respondent elicited through direct questions. The complete questionnaire can be found in Appendix A.

3.2. Data analyses

First, we conducted descriptive analyses to assess the importance farmers consider biological control to have, for croplands in general as well as for their own orchards. For this, farmers' responses were classified according to whether they spoke about direct benefits resulting from biological control (e.g. elimination of pests) or indirect benefits (such as increased yield or quality) benefits. In addition, descriptive analyses were also conducted to determine the percentage of farmers that had sighted, knew about and recognized the different taxa they were asked about in the questionnaire as natural enemies.

Second, to measure the importance farmers ascribed to each taxon in terms of providing biological control, we created a *biological control index,* a measure of the average capacity of a particular natural enemy to provide biological control as perceived by farmers. Then, we conducted Spearman's correlation tests to ascertain whether there was a relationship between each species' rating in the *biological control index* and the percentage of farmers that had sighted it, knew what it was and/or recognized it as natural enemy.

Third, we estimated the contribution of each taxon to biological control according to farmers' perceptions of pest-natural enemy interactions using network analysis. In the network, nodes represent pests and natural enemies. For natural enemies, we calculated (1) the weighted degree, i.e. the number of relationships between two nodes weighted by the size of the edges (Borgatti and Everett, 1997) and (2) the betweenness, i.e. how many times a node relates to other nodes to which it would otherwise not be connected (Freeman, 1978; Scott et al., 1996). We used Gephi software to create the networks (Bastian et al., 2009) and NodeXL for their visualization (Smith et al., 2010). To test the association between farmers' perceptions of the importance of each natural enemy and their perceptions of interaction between natural enemies and pests, we conducted Spearman's correlations between the *biological control index* and the weighted degree and betweenness. All Spearman's correlation tests were performed with the 'cor.test' function in the 'stats' (version 3.3.2) package, using the statistical software R version 3.3.3 (www.r-project.org).

Fourth, to analyze what effect the farming and socio-economic characteristics of the respondents had on their perception of natural enemies as providers of biological control, we used generalized linear models (GLMs) and redundancy analysis (RDA). Table 1 shows the explanatory variables used in the two analyses. To conduct the GLM, we created the dependent variable *Natural enemy awareness*, a measure of the number of taxa farmers correctly recognized as natural enemies in their own cider-apple orchards. We performed a stepwise-forward regression procedure to identify the best model according to Akaike (Zhang, 2016). We used the 'glm' function in the package 'stats' (version 3.3.2).

The RDA examined the relationships between the *biological control index* estimated for all natural enemies (dependent variables) and farming and socio-economic characteristics (explanatory variables; see Table 1). To find the best model, we used automatic stepwise model building based on permutation tests (Blanchet et al., 2008). Two

Table 1
Description of farming and socio-economic variables. (Y = Yes; N = No; nl = natural logarithm).

Farming and socio-economic variables	Description
Full-time farmer	Works full time, only in agriculture (Y/N)
Part-time farmer	Also has another job not related to agriculture (Y/N)
Farms for leisure and tradition	Cultivates apples for tradition and hobby reasons (Y/N)
Time working in agriculture	Years spent working in aspects of agriculture (nl)
Home-gardener	Cultivates fruit and vegetables for self-supply (Y/N)
Market for produce	Destination of the harvest: mass marketing, local scale, self-supply (rank 1 to 3)
Orchard size	Orchard area in hectares (nl)
Education level	Educational qualifications achieved by farmers (rank 1 to 5)
Membership of association	Membership of association or organization of agriculture nature (Y/N)
Herbicide use	Under trees (some farmers) or in the whole orchard (Y/N)
Insecticide use	Use of insecticides to control various pests (Y/N)
Use of chemical fertilizers	Use of chemical fertilizers to improve yield (at least once a year) (Y/N)

variables were omitted: (1) *membership of an association* and (2) *use of chemical fertilizers*. The significance of the RDA was tested with a Monte Carlo permutation test (999 iterations). The RDA was performed with the 'rda' function in the package 'vegan' (version 2.4-2).

Before applying both the GLM and the RDA we tested for linear dependencies among the explanatory variables using the variance inflation factors (VIF) (Belsley, 1991). To avoid heteroscedasticity, we log-transformed the continuous explanatory variables (*time working in agriculture* and *orchard size*).

4. Results

4.1. Importance of biological control and natural enemies

Most farmers (90%) considered natural enemies important for croplands, while only 55.6% of farmers considered them important for their own cider-apple orchards. The most important benefits of natural enemies were considered to be that they killed pests and were an alternative to pesticides, both of them direct benefits. Some indirect benefits were, however, also mentioned by a small number of respondents: to improve crop quality, to increase yield and that they were essential for production (Fig. 2).

The percentage of natural enemy taxa that farmers had seen was higher than the percentage they knew about or recognized as natural enemies (94.3%, 88.7% and 57.7% of farmers, respectively). Earwig (*Forficula auricularia*) was the taxon that farmers had seen least in their orchards (77.8%) and hoverfly, tit and earwig were those farmers least knew about (17.8%. 64.4% and 66.7%, respectively). Earwig and hoverfly were also the least recognized natural enemies (12.2% and 7.8% respectively). By contrast, the ladybug (*Coccinella septempunctata*) and the vertebrates were the most recognized natural enemies (ranging from 61.1% to 93.3%). Interestingly, all taxa that are not natural enemies, except the land slug (*Arion ater*), were mistakenly identified by some farmers as natural enemies: stag beetle (*Lucanus cervus*) (by 12.2%), bumblebee (*Bombus terrestris*) (7.8%) and magpie (*Pica pica*) (24.4%) (Fig. 3). Finally, 37.8% of farmers also named other species they considered important for biological control: 26.0% mentioned nocturnal raptors (e.g. *Tyto alba, Strix aluco, Athene noctua*) and bats, and 13.3% mentioned various other mammals (e.g. *Mustela nivalis, Mustela erminea, Martes martes/foina, Meles meles* and *Erinaceus europaeus*) (Fig. 3).

4.2. Perceptions of natural enemies as providers of biological control

Birds (except blackbird and woodpecker) and ladybug were the natural enemies with the highest *biological control index*. By contrast, hoverfly, earwig and spider had the lowest (Fig. 4). Whilst *biological control index* of a taxon was not correlated with the percentage of farmers who had seen it (*Spearman's rho* = 0.375, $p = 0.288$; Fig. 4a) or knew about it (*Spearman's rho* = 0.313, $p = 0.381$; Fig. 4b), it was, however, significantly positively correlated with the percentage of farmers who recognized it as a natural enemy (*Spearman's rho* = 0.927, $p < 0.001$; Fig. 4c).

The network in Fig. 5 shows that farmers perceived a high number of connections between natural enemies and pests. Based on the network, farmers perceived the robin (*Erithacus rubecula*), tit, buzzard and ladybug as the most important natural enemies and the fossorial water vole, rosy apple aphid, green aphid and woolly apple aphid as the most serious pests (Fig. 5a, Table B2 for more details). A clique comprised of two natural enemies -buzzard and fox (*Vulpes vulpes*)- and two pests –fossorial water vole and roe deer (*Capreolus capreolus*) is also evident. In addition, we found that farmers perceived trophic interactions that do not in fact exist, such as between magpie, blackbird or woodpecker and several invertebrate pests (e.g. aphids, green weevil and blossom weevil) (Fig. 5a).

The taxa with the highest weighted degrees were robin and tit, while buzzard and tit had the highest betweenness (Fig. 5b and c). We found significant correlations between the weighted degree and betweenness and *biological control index* (Weighted degree: *Spearman's rho* = 0.818, *p*

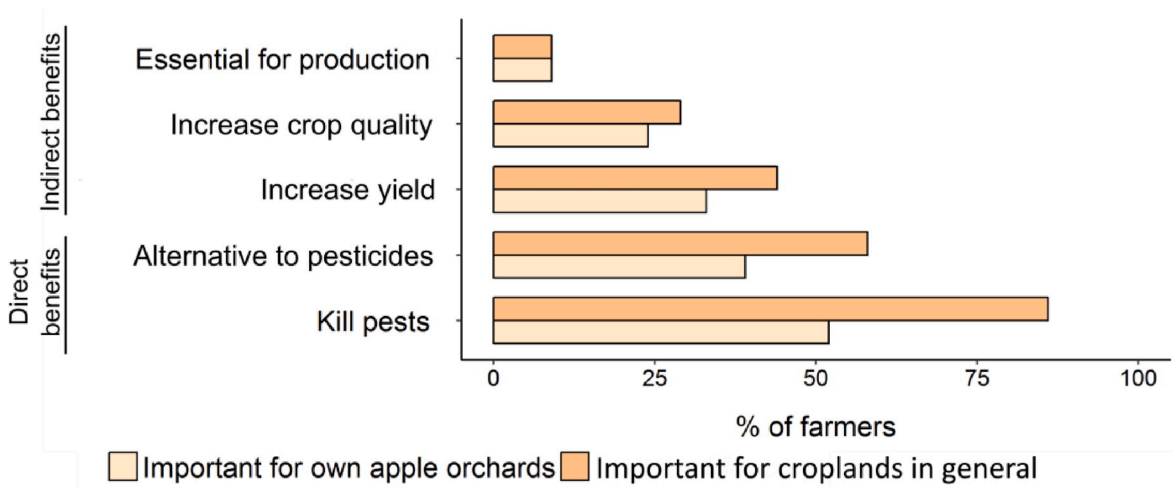

Fig. 2. Benefits of natural enemies identified by farmers for croplands in general and in their own cider-apple orchards.

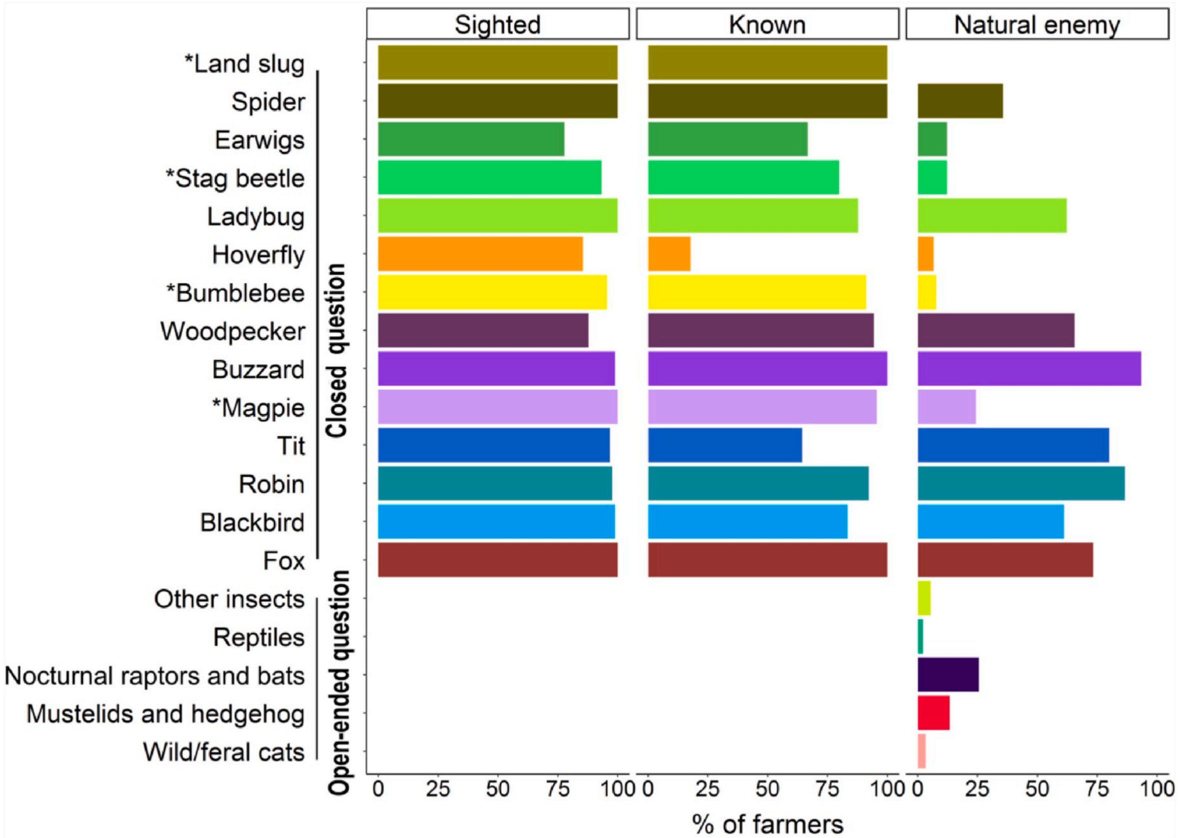

Fig. 3. Bar diagram representing, above, the percentage of farmers that had seen and/or knew about each taxon and/or considered it to be a natural enemy (information from closed question) and, below, other taxa mentioned as being natural enemies (open-ended question). The different colors and shades indicate taxonomic affinity: olive green – Gastropods; dark olive green – Arachnids; shades of bright green, orange and yellow – Insects; shades of blue – Birds; shades of reds-Mammals. * indicates a taxon that is not actually a natural enemy. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

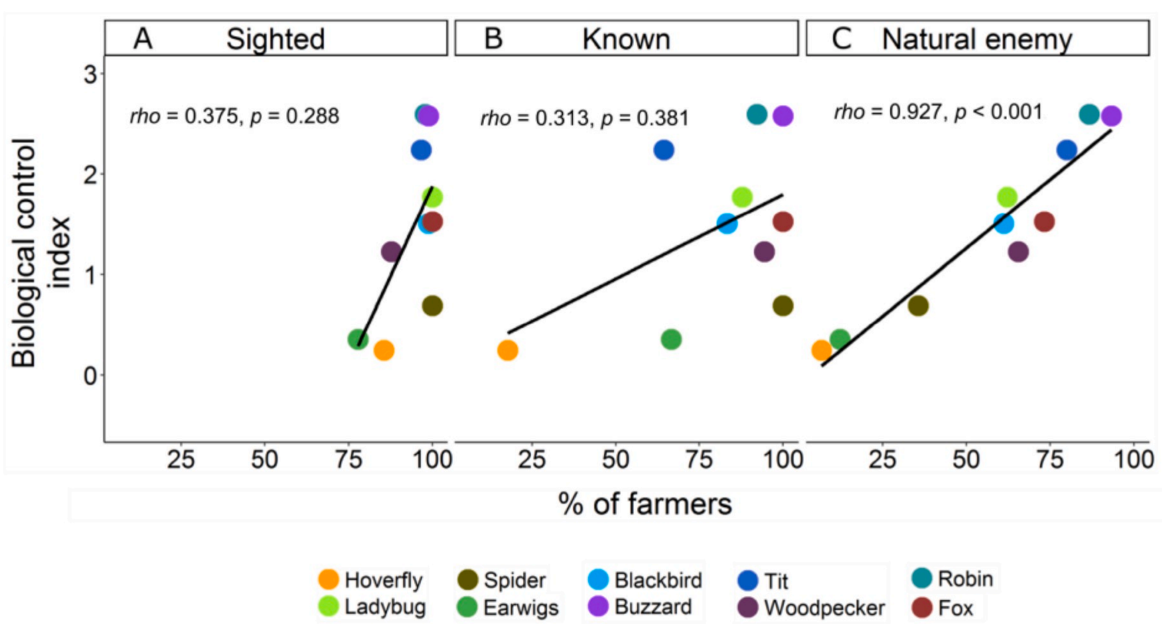

Fig. 4. Correlations between *biological control index* (i.e. perceived importance of natural enemy as biological control) and percentage of farmers that (A) had seen and/or (B) knew of the taxon and (C) considered it a natural enemy.

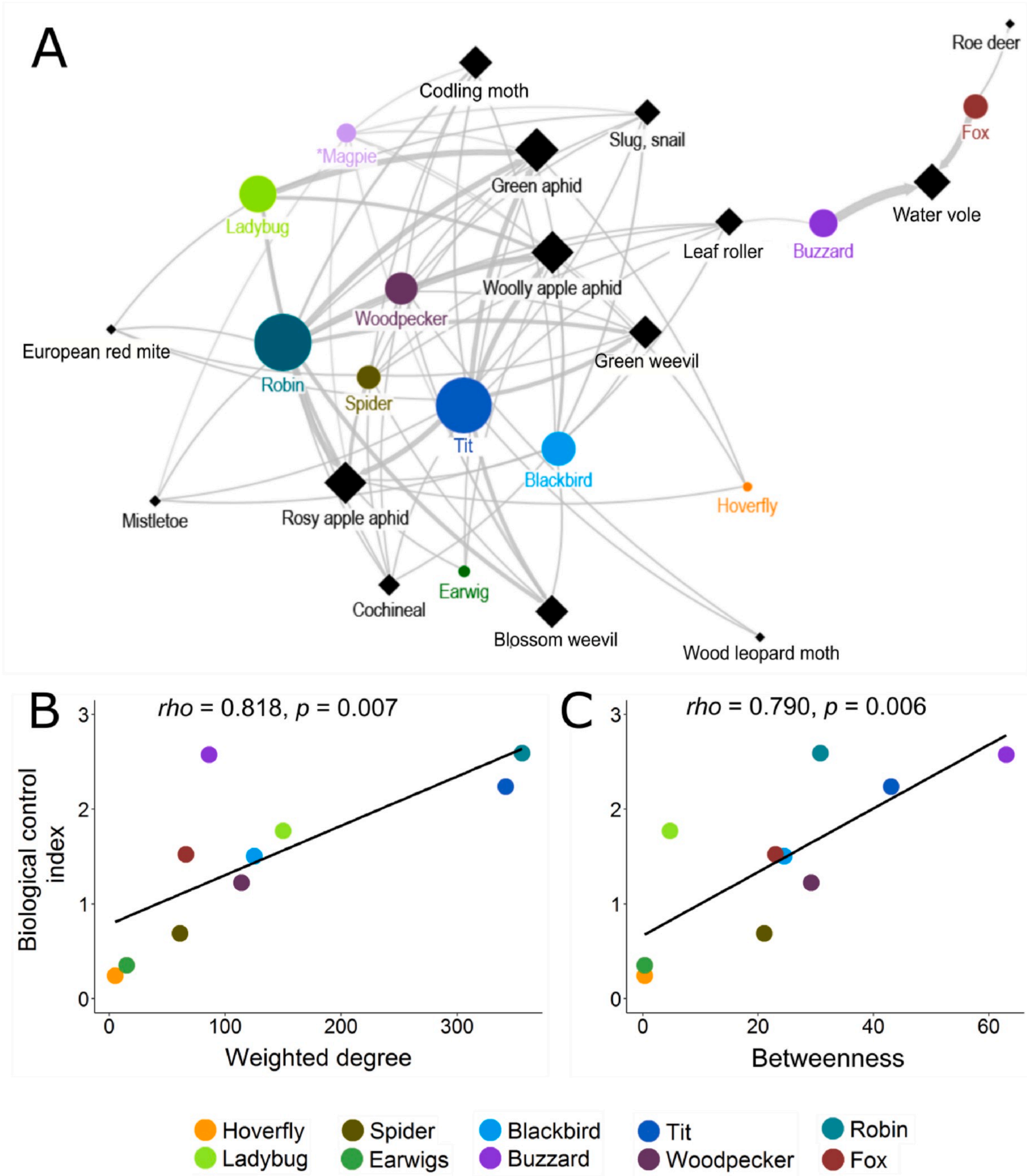

Fig. 5. (A) Network created from farmers' perceptions of the contribution of different natural enemies to pest control (circles represent natural enemies, diamonds represent different pests; the size of the node represents the weighted degree; the line width is proportional to the number of farmers that mentioned the predation relationship). (B and C) Correlations between the *biological control index* of each taxon and (B) weighted degree and (C) betweenness of nodes (i.e. natural enemies) calculated from network analysis.

= 0.007; Betweenness: *Spearman's rho* = 0.790, $p = 0.006$; Fig. 5b and c).

4.3. Farming and socio-economic characteristics

Natural enemy awareness was significantly affected by the farming and socio-economic characteristics of the farmers surveyed ($F = 8.557$, $p < 0.001$) (Table 2). *Education level, time working in agriculture* and *being a full- or part time farmer* had a positive effect on *natural enemy awareness* (Table 2).

The RDA showed statistically significant associations between farming and socio-economic characteristics and *biological control index* ($p = 0.007$, from 999 permutations). The first two axes explained 61.6% of the total variance (Table 3). The first RDA axis (34.9% of the variance) showed an association between the *biological control index* of tit, robin, ladybug, spider, earwig and fox (in the positive scores) and working in larger orchards and using herbicides. The second axis (26.7% of the variance) represented in its positive scores the association between the *biological control index* of robin with part-time farmers who have worked for longer periods in agriculture. The negative scores of the second axis represent an association between the *biological control index* of blackbird, woodpecker, buzzard and hoverflies with farmers working in larger orchards (Table 3).

Table 2
Results of the multivariate regression analysis of farmers' *Natural enemy awareness*.

Variables	Full model		Reduced model	
	Coefficient + (SD)	Significance	Coefficient + (SD)	Significance
Full-time farming	0.402 (0.161)	0.015	0.464 (−0.137)	0.001
Part-time farming	0.281 (0.111)	0.013	0.346 (0.1)	0.001
Time working in agriculture	0.119 (0.075)	0.118	0.179 (0.069)	0.011
Education level	0.123 (0.0334)	< 0.001	0.131 (0.029)	< 0.001
Insecticide use	−0.171 (0.104)	0.102	−0.158 (0.091)	0.084
Farms for leisure and tradition	0.231 (0.131)	0.082		
Home-gardener	0.001 (0.109)	0.994		
Market for produce	0.03 (0.075)	0.685		
Orchard size	0.093 (0.072)	0.2		
Membership of association	0.057 (0.099)	0.568		
Herbicide use	0.103 (0.105)	0.33		
Use of chemical fertilizers	−0.159 (0.102)	0.123		
R^2	0.388		0.337	
Adjusted R^2	0.292		0.298	
F	4.060	< 0.001	8.557	< 0.001
AIC	112.933		106.001	

Table 3
Results of the redundancy analysis showing the influence of farming and socio-economic characteristics on *biological control index* estimated for different taxa perceived as natural enemies by farmers. Explanatory variables with a *p*-value <0.05 after stepwise model building are in bold.

Dependent variables	Axis 1	Axis 2
Tit	**0.631**	0.278
Blackbird	0.275	**−0.434**
Woodpecker	0.198	**−0.397**
Robin	**0.607**	**0.599**
Buzzard	0.289	**−0.452**
Ladybug	**0.482**	−0.245
Hoverfly	0.079	**−0.081**
Spider	**0.309**	−0.078
Earwig	**0.184**	−0.034
Fox	**0.310**	−0.181
Explanatory variables		
Full-time farming	0.187	0.001
Part-time farming	0.014	**0.077**
Farming for leisure and tradition	−0.106	0.239
Time working in agriculture	−0.076	**0.261**
Home-gardener	−0.202	0.009
Market for produce	0.176	−0.009
Orchard size	**0.331**	**−0.206**
Education level	0.268	−0.134
Herbicide use	**0.329**	0.135
Insecticide use	0.007	−0.091
RDA statistics		
Eigenvalue	0.420	0.321
Variance explained (%)	34.910	26.714
Cumulative variance (%)	34.910	61.624

5. Discussion

In this study we characterized farmers' perceptions and knowledge of different natural enemies and the contributions each makes to biological control in Asturian cider-apple orchards. These cider-apple orchards are extensive or semi-extensive agroecosystems where various taxa contribute to biological control (i.e. insects, arachnids, birds, mammals; Miñarro et al., 2011). However, the results of the survey showed that farmers considered biological control to be less important in cider-apple orchards than in croplands in general (Fig. 2). This difference might be explained by the fact that for cider production, a degree of damage to the apples is permissible, meaning that farmers tolerate a greater level of pests in apple orchards than they would tolerate (or would expect others to) in other crop production systems. In addition, not all cider production in this region is professionalized and home production and consumption is common. A similar tolerance for pests was found by Morales and Perfecto (2000), who concluded that some farmers do not consider insects as a pest until the damage they cause results in economic loss. Nevertheless, awareness of biological control in cider-apple farmers is higher than in many of those working with other crops around the world given that nearly 70% of farmers worldwide have no knowledge of the concept (Wyckhuys et al., 2019).

We found that a higher number of farmers perceived the direct benefits (i.e. kill pests and alternative to pesticides) of natural enemies than the indirect benefits (i.e. increase yield and improve quality) (Fig. 2). This might lead to an underestimation of the role of natural enemies for biological control in orchards and their contribution to cider production. Previous research has found that an increased awareness of the benefits derived from ecosystem services can contribute to enhancing biodiversity conservation (Bennett, 2016). Future campaigns from government agencies, training providers and farming associations should promote farmers' awareness of the benefits, both direct and indirect, provided by natural enemies in cider-apple orchards.

We found that the recognition of animals as natural enemies varies across taxonomic groups (i.e. birds, mammals, insects, arachnids). While farmers easily recognized birds and mammals as natural enemies, arachnids and insects were poorly recognized (with the exception of the ladybug) (Fig. 3). This is in line with previous research that found that vertebrates are easier to observe than invertebrates (Martín-López et al., 2007; Willemen et al., 2015), which is due not only to body size but also to the former's greater capacity for movement (Tscharntke et al., 2008). For example, birds spill-over into crop fields from surrounding habitat patches and vice versa, often using orchards for several resources (i.e. nesting, feeding, protection) (García et al., 2018). Some vertebrates are also easily recognized because they are part of the local folk culture (Berlin, 1992), meaning knowledge of on-farm animals is probably shaped not only by the conspicuousness of the animal itself, but also by farmers' cultural knowledge (Bentley and Rodríguez, 2001; Bentley and Baker, 2005). However, in fact, in this work recognition of a taxon as a good natural enemy was not correlated with having seen or knowing about the creature involved, but rather with farmers' knowledge and ability to recognize it as a provider of biological control (Fig. 4). This supports previous research on perceptions of regulating services provided by scavengers (Morales-Reyes et al., 2018).

In addition, we found that within each large taxonomic group, identification of the individual taxa as natural enemies varied considerably. For instance, whilst robin and tit were recognized as very important natural enemies, the importance given to woodpecker was much less (Fig. 4). These differences could be explained by farmers' daily interactions with biodiversity in cider-apple orchards and their local ecological knowledge. First, farmers probably notice those natural enemies that are more abundant and thus more visible (Okonya and Kroschel, 2016; Wyckhuys and O'Neil, 2007). For example, robin and tit were frequently recognized and well valued as natural enemies, and, in fact, these are the most abundant species in these cider-apple orchards (García et al., 2018). In addition, abundant species tend to contribute more to the provision of a particular ecosystem service than rare species (Díaz et al., 2011; Winfree et al., 2015).

In addition to the effect of certain traits of an animal (e.g. body size or abundance) on farmers' perceptions of organisms as natural enemies within the orchard, knowledge acquired from external sources, such as scientific outreach, newspaper coverage, and social media, may also have an effect. For example, an outreach campaign by García et al. (2018), which included seminars for apple farmers and articles in the press, might have contributed to raising awareness of the importance of insectivorous birds as providers of biological control. In addition, certain species are more likely to feature in press coverage on biological control and this may well affect farmers' perceptions. For example, ladybug appears more often in magazine articles related to biological control than other invertebrates (Riddick, 2017), and since 'people care about what they know' (Balmford et al., 2002, pp. 2367), this may explain why we found that ladybug was more often recognized as a natural enemy than other invertebrates. Newspaper and media coverage is also known to impact on public perceptions of biodiversity and the social acceptance of wildlife (Schakner et al., 2019; Fernández-Gil et al., 2016), and the higher likelihood of vertebrates rather than invertebrates featuring in news coverage and social media (Kidd et al., 2018; Willemen et al., 2015) might also play its part in explaining our results. Reassuringly, some authors have identified ways of enhancing farmers' knowledge of biological control by using external sources and channels of communication: digital apps (Van Mele et al., 2018), outreach videos (Bentley et al., 2019), and participatory and transdisciplinary research approaches (Šūmane et al., 2018).

The results of this work show that Asturian apple farmers have a complex understanding of the interactions between natural enemies and pests (Fig. 5a). Those taxa perceived as more important for biological control also had higher weighted degree and betweenness (Fig. 5b and c). For example, the robin and the tit were identified as important natural enemies and were considered to prey on many pests. This is in accordance with research demonstrating that both species are generalist natural enemies (Ceia and Ramos, 2016). The buzzard, on the other hand, while considered by the respondents to be important for biological control, had low weighted degree but the highest betweenness. This may be because the farmers knew that the buzzard preyed on fossorial water vole, which is the most serious and well-known pest in local apple folk culture (Table B2), but mistakenly thought that it also predates leaf roller, resulting in its high betweenness value and it connecting the clique comprised by mammals with the main network (Fig. 5). Farmers also "over-estimated" the biological control capabilities of certain organisms: for example, blackbird and woodpecker preying on aphids and magpie preying on various arthropods. However, at the same time they also "under-estimated" the potential of specific taxa: for example, earwig and spider are perceived to predate on a limited number of pests despite them being generalists (Cross et al., 2015) and hoverfly is not perceived as a natural enemy by farmers. Both cases show that farmers critically misunderstand the role of those organisms for biological control.

Furthermore, we found that farming and socio-economic characteristics also influence farmers' perception of and knowledge about biological control and natural enemies. Time spent in agriculture and working full- or part time in farming increased the number of taxa correctly identified as natural enemies (Table 1). This is in line with other works where farming experience has been identified as key to the local ecological knowledge required for sustainable agricultural practices (Gómez-Baggethun et al., 2010; Iniesta-Arandia et al., 2015; Oteros-Rozas et al., 2013), and those investigating farmers' knowledge of ecosystem services in Spain (Morales-Reyes et al., 2018, 2019). In addition, we found that farmers with higher educational qualifications correctly identified more taxa as natural enemies (Caballero-Serrano et al., 2017; Lewan and Söderqvist, 2002; Martín-López et al., 2012), confirming the findings of Wyckhuys and O'Neil (2007) that to improve farmers' knowledge of natural enemies, environmental education programs are essential.

Finally, our results also support the idea that both knowledge systems, formal and local ecological knowledge, are important for building perceptions of natural enemies (Table 2). For example, owners of larger orchards who used herbicides correctly identified a wider variety of taxa as providers of biological control. Assuming that owning bigger orchards means the farmers are more likely to work full- or part time on the land, rather than, for example, seeing it as a hobby, they most likely have acquired considerable knowledge, either formally (courses, trade magazines or workshops) or informally (local ecological knowledge). This might mean that the hybridization between formal and local ecological knowledge might allow farmers to recognize the biological control importance of more species. These results support the recent claims of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystems Services (IPBES) that both types of knowledge need to be addressed in order to support environmental management and biodiversity conservation (Hill et al., 2017; Tengö et al., 2014).

This study shows that the consideration of farmers' perceptions and knowledge in scientific research of natural enemies can shed light on how farmers engage in actions to foster biodiversity conservation and sustainable food production in agroecosystems (Rawluk and Saunders, 2019). Yet, this study has some limitations to achieve the above-mentioned goal since it does not consider other relevant aspects, such as level of empowerment, engagement and trust (Kusnandar et al., 2019). A second limitation is that perceptions are often contextual, they can change and being influenced by different forces (e.g. markets, industries, global trends). In fact, perceptions are often dismissed in conservation and environmental management because they are considered inaccurate place-based "experiential knowledge" (Bennett, 2016). Yet, we argue that studies about farmers' perceptions can provide important insights of understandings and interpretations of ecosystem services and the ways by which biodiversity provide them. In addition, studies about farmers' perceptions can contribute to understand how to promote acceptability of environmental management (Bennett, 2016). To overcome the limitations posed by the research of perceptions, future studies should also research other social components, such as attitudes, behaviour, norms and governance (Bennett et al., 2017). In the context of the EU Common Agricultural Policy beyond 2020, it is urgent to understand how farmers interpret ecosystem services, how they are willing to engage in sustainable agricultural practices and how institutions can reinforce sustainable behaviours.

6. Conclusions

Asturian cider-apple farmers are aware of the importance of natural enemies and biological control for general crop production. However, they "under-estimate" the importance of biological control for their own cider-apple orchards. Key benefits provided by natural enemies, such as improving crop quality and increasing yield are not acknowledged by many farmers. Although they clearly had knowledge of many of the taxa that act as natural enemies, we found some important knowledge gaps and misunderstandings. While farmers identified certain taxa (i.e. robin, great tit, buzzard, fox, ladybug) as important for biological control, they also did not recognize other important taxa related to cider-apple production (i.e. woodpecker, hoverfly, spider, earwig). Thus it can be seen that prevailing perceptions (farmers' ecological knowledge) are inadequate and insufficient to tackle certain pests (e.g. woolly apple aphids or codling moth) using biological control. Our findings show that those farmers economically dependent on cider-apple orchards (working full- or part time in the sector), with higher educational levels and knowledge acquired through working in cider-apple orchards recognized a higher number of natural enemies. Although farmers' perceptions of biological control and natural enemies are complex and influenced by multiple factors, our results suggest that their perceptions are shaped by both their local ecological knowledge and external sources. Based on these results and in order to promote biological control in cider-apple orchards, we suggest that future actions pertaining to orchard management should take into account improving farmers' knowledge of biological control and natural enemies, particularly for those that are less visible (for example insects) or more difficult to identify. In addition, orchard management practices should promote traditional farming systems that contribute to preserving local ecological knowledge and support the setting up or maintenance of farmer networks through which knowledge regarding biological control can be shared.

Author contributions

All authors were involved in designing the study. RMS collected the data. RMS and BML analyzed the data and wrote the first versions of the manuscript. All authors contributed to the manuscript writing.

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.

CRediT authorship contribution statement

Rodrigo Martínez-Sastre: Methodology, Data curation, Formal analysis, Writing - original draft, Writing - review & editing, Visualization. **Daniel García:** Methodology, Writing - review & editing. **Marcos Miñarro:** Methodology, Writing - review & editing. **Berta Martín-López:** Methodology, Formal analysis, Writing - original draft, Writing - review & editing.

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Appendix A. Supplementary data

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