THE FUNCTIONAL AGROBIODIVERSITY IN THE DOURO DEMARCATED REGION VITICULTURE: UTOPIA OR REALITY? ARTHROPODS AS A CASE-STUDY -A REVIEW

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A AGROBIODIVERSIDADE FUNCIONAL NA VITICULTURA DA REGIÃO DEMARCADA DO DOURO: UTOPIA OU REALIDADE? OS ARTRÓPODES COMO CASO DE ESTUDO – REVISÃO

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SUMMARY

Aiming to reduce the losses of biodiversity and the degradation of associated ecosystem services, the United Nations established the 2011-2020 period as the UN Decade on Biodiversity. During this period, the countries involved compromised on implementing the Strategic Plan for Biodiversity, including the Aichi Biodiversity Targets. The argument is that biological diversity underpins the functioning of ecosystems and the provision of services essential to human well-being, further contributing to economic development and the achievement of the Millennium Development Goals. The purpose of this review is to present results of research and academic works carried out over several years in the Douro Demarcated Region in the field of functional agrobiodiversity, understood as the part of ecosystem biodiversity that provides ecosystem services, which support sustainable agricultural production and can also bring benefits to the regional and global environment and to society as a whole. Such studies specifically aimed to contribute knowledge about the diversity of arthropods in the vineyard ecosystem and about practices that can increase their abundance, diversity and services provided. In this context, a general characterization of the arthropod community identified in the vineyard ecosystem is conducted, complemented by information on the role played, by the taxonomic groups identified. The importance of increasing arthropod populations, the vegetation of vineyard slopes, and the existence of shrubs, forests and hedgerows next to the vineyards is discussed. The fundamental role of soil management practices is also referred, namely that of ground cover and the application of compost from winery wastes in the abundance and diversity of these organisms populations. Finally, bearing in mind the importance of the use of this information by vine growers, the measures taken for its dissemination are also presented.

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RESUMO

Com o objetivo de reduzir a perda de biodiversidade e a degradação dos serviços ecossistémicos associados, as Nações Unidas estabeleceram o período 2011-2020 como a Década da Biodiversidade. Durante este período, os países envolvidos comprometeram-se a implementar o Plano Estratégico para a Biodiversidade, incluindo as Metas de Biodiversidade de Aichi. O argumento é o de que a diversidade biológica sustenta o funcionamento dos ecossistemas e a provisão de serviços essenciais ao bem-estar humano, contribuindo ainda para o desenvolvimento económico e a concretização dos Objetivos de Desenvolvimento do Milénio. A presente revisão tem por objetivo apresentar resultados obtidos no decurso de projetos de investigação e trabalhos académicos, desenvolvidos ao longo de vários anos na Região Demarcada do Douro, no domínio da agrobiodiversidade funcional, entendida como a parte da biodiversidade dos ecossistemas que faculta serviços essenciais à produção agrícola sustentável e que também pode proporcionar benefícios ambientais à escala regional e global e à sociedade em geral. Com estas atividades pretendeu-se, mais especificamente, obter conhecimento sobre a diversidade de artrópodes existentes no ecossistema vitivinícola e sobre práticas capazes de incrementarem a sua abundância, diversidade e serviços facultados. No contexto referido, procede-se a uma caracterização geral da comunidade de artrópodes identificados no ecossistema vitivinícola, complementada com informação sobre o papel desempenhado pelos diferentes grupos taxonómicos identificados. Discute-se a importância, no incremento das populações de artrópodes, da vegetação dos taludes da vinha, e da existência de matos, florestas e sebes na sua proximidade. Também se refere o papel fundamental desempenhado, na abundância e diversidade das populações destes organismos, das práticas de condução do solo, designadamente do enrelvamento e da aplicação de compostados provenientes dos resíduos da adega. Finalmente, e tendo em atenção a importância do uso desta informação pelos viticultores, apresentam-se as iniciativas que têm sido usadas na sua divulgação.

Key words: biodiversity, vineyard, ecological infrastructures, ground cover.
Palavras-chave: biodiversidade, vinha, infraestruturas ecológicas, cobertura do solo.

INTRODUCTION

In 1992, at the first Earth Summit, held in Rio de Janeiro (Brazil), most of the represented nations recognized that ecosystems were being destroyed and biodiversity was being lost at an alarming rate (Cardinale *et al*., 2012). After almost two decades, based on the understanding that biological diversity underpins the functioning of ecosystems and the provision of services essential to human well-being, the United Nations established the period of 2011-2020 as the UN Decade on Biodiversity, under the slogan "Living in Harmony with Nature", with the aim of reducing the losses of biodiversity and the degradation of associated ecosystem services as well as their impact on humanity (Secretariat of the Convention on Biological Diversity, 2014). During this period, the countries involved compromised on implementing the Strategic Plan for Biodiversity, including the Aichi Biodiversity Targets. The Strategic Plan for Biodiversity addresses five main strategic goals, namely: 1) *address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society*; 2) *reduce the direct pressures on biodiversity and promote sustainable use*; 3) *improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity*; 4) *enhance the benefits to all from biodiversity and ecosystem services*; 5) *enhance implementation through participatory planning, knowledge management and capacity building* (Secretariat of the Convention on Biological Diversity, 2014). The main objective was to break the loss of biodiversity so that by 2020, ecosystems would be resilient and would continue to provide essential services, thus safeguarding the planet's biodiversity and contributing to human well-being and the eradication of poverty (Secretariat of the Convention on Biological Diversity, 2014).

Functional agrobiodiversity is defined as '*those elements of biodiversity on the scale of agricultural fields or landscapes, which provide ecosystem services that support sustainable agricultural production and can also deliver benefits to the regional and global environment and the public at large*' (ELN-FAB, 2012). Examples of these ecosystem services are: the provision of food, fibre and water, the regulation of diseases, floods and climate, pollination, the degradation of organic matter and nutrient cycling, the suppression of pests, and services associated with recreation or education (Millennium Ecosystem Assessment, 2005).

Invertebrates, including arthropods, are part of the functional agrobiodiversity and provide numerous ecosystem services, including pollination, biological control of pests, soil aeration and waste decomposition (reviewed by Saunders, 2018).

The acknowledgement of biodiversity as an important element of agricultural production and the identification of elements which deliver significant ecosystem services will help predict how changes in the environment and management practices will impact the multiple ecosystem services provided by agroecosystems (reviewed by Wood *et al*., 2015). Additionally, it will increase crop productivity in a sustainable manner, with a lower dependence on external inputs (ELN-FAB, 2012; Sandhu *et al*., 2015).

It is known that landscape management and farming practices can contribute to the conservation and enhancement of biodiversity (of plants, animals, fungi, etc.) as well as of the ecosystem services provided. Examples of these farming practices are the maintenance of non-crop vegetation such as field margins, forests, hedgerows and other non-crop elements, the use of conservation tillage and crop diversification (ELN-FAB, 2012). Other practices such as the use of organic fertilizers (manures) and the retention of crop residues also promote biodiversity in general and soils' health in particular (Lehman *et al*., 2015).

As far as arthropods are concerned, it is known that their abundance and diversity depends on the large-scale structure and composition of landscapes, normally constituted of a mosaic of crop and non-crop elements (Gardiner *et al*., 2009a,b). Also, the biological control of pests, an important ecosystem service provided by arthropods, is reduced in simplified agricultural landscapes (Rusch *et al*., 2016). Moreover, the vegetation cover in inter-rows improves biodiversity by benefitting the activity and providing habitat for many different species in the soil and above ground.

In the Douro Demarcated Region (DDR), located in Northern Portugal, vineyards occupy 43,500 ha (about 17.6% of the total area of the region) (IVDP, 2018). The DDR landscape also includes important areas of natural or semi-natural habitats, including structures nowadays designated as "mortórios", which are old terraces built prior to the 1860s, before the devastation of the Douro vineyards by the phylloxera, and which were later abandoned (Andresen *et al*., 2004). These areas are extremely important from a biological diversity standpoint (Andresen *et al*., 2004), as they provide a natural habitat for many plant and animal species.

In 2001, the "Alto Douro Vinhateiro" (ADV) (one part of the DDR with about 24,600 ha) was included in the list of UNESCO World Heritage Sites as an evolving and living cultural landscape. Currently, its authenticity prevails, and sustainable solutions are being implemented according to the condition of scarce resources – water and fertile soil – and steep slopes (Andresen and Rebelo, 2013).

Since 2010, various studies have been conducted in the DDR within research projects and academic works, in order to evaluate the impact of elements from landscape and farming practices on the conservation and enhancement of biodiversity and associated ecosystem services. The aims of this review are to synthesize the main results obtained and also, provide a framework for functional agrobiodiversity management in vineyards that can be used and improved by farmers, technicians, and stakeholders.

GENERAL CHARACTERIZATION OF THE ARTHROPODS ASSEMBLAGE IDENTIFIED AND THE ECOSYSTEM SERVICES PROVIDED

On the whole, eight classes of arthropods have been reported in the Douro Demarcated Region: Arachnida, Chilopoda, Diplopoda, Entognatha, Insecta, Malacostraca, Pauropoda, and Symphyla. Some of the identified species are Iberian endemism, specifically *Castianeira badia* (Figure 1A), *Eratigena bucculenta*, *E. feminea*, *E. montigena*, *Nemesia athiasi*, *Oecobius machadoi*, *Tegenaria ramblae*, *Zodarion alacre*, and *Z. duriense*, from Araneae; *Cataglyphis hispanica*, *C. iberica*, and *Aphaenogaster iberica* (Figure 1B) from Formicidae (Gonçalves *et al*., 2017; Carlos *et al*., 2019); *Gluvia dorsalis* from Solifugae (Figure 1C) and *Sciobia lusitanica* from Gryllidae (Figure 1D) (Gonçalves *et al*., 2018a).

Figure 1. Arthropods endemic of the Iberian Peninsula, collected in the Douro Demarcated Region: *Castianeira badia* (Araneae: Corinnidae) (A), *Aphaenogaster iberica* (Formicidae) (B), *Gluvia dorsalis* (Solifugae) (C), and *Sciobia lusitanica* (Gryllidae) (D). Authorship: F. Gonçalves/ UTAD

Artrópodes endémicos da Península Ibérica observados na Região Demarcada do Douro: Castianeira badia (Araneae: Corinnidae) (A), Aphaenogaster iberica (Formicidae) (B), Gluvia dorsalis (Solifugae) (C) e Sciobia lusitanica (Gryllidae) (D). Autoria: F. Gonçalves/ UTAD

In the soil-surface, the arthropod assemblages which stood out for their abundance were the omnivores (Formicidae) and detritivores (mainly Collembola and Oribatid mites), followed by predators (mainly Araneae, Carabidae and Staphylinidae) and phytophagous (mainly Formicidae, Curculionidae and Gryllidae) (Gonçalves *et al*., 2017; Carlos et al., 2019). Standing out among the soil-living arthropods were the detritivores (Collembola and Oribatid mites) and predators (Mesostigmatid and Prostigmatid mites) (Gonçalves, unpublished date). In arthropod assemblages from vegetation, the most abundant were the phytophagous (mainly Cicadellidae, Lygaeidae and Chrysomelidae), as well as parasitoids (mainly Chalcidoidea, Braconidae and Ichneumonidae) and predators (mainly Coccinellidae, Araneae and Carabidae) (Carlos, 2017).

Among the Formicidae, *Aphaenogaster gibbosa*, *A. iberica*, *Messor barbarus*, *Pheidole pallidula* (from Myrmicinae), *Cataglyphis hispanica*, *C. iberica*, *Plagiolepis pygmaea* (from Formicinae), and *Tapinoma nigerrimum* (from Dolichoderinae) were the most abundant species found in the soil-surface (Gonçalves *et al*., 2017; Carlos *et al*., 2019). The Formicidae family has an important role in ecosystems through their diverse ecological functions, mainly as biological regulators and ecosystem engineers (Ward, 2006). Through their activity, they modify the physical, chemical and microbiological properties of the soil (Dostál *et al*., 2005; Jouquet *et al*., 2006). Although most species are omnivorous and generalists (Cerdá and Dejean, 2011), others present different eating behaviours: some are generalist predators, others are phytophagous or detritivores by cutting up leaves into smaller components, and thus accelerating the decomposition process; others feed on honeydew, pollen and extrafloral nectar (reviewed by Gonçalves *et al*., 2017).

Some ants are involved in mutualistic relationships with hemipterans (e.g. mealybugs, scale insects, aphids). In this way, they obtain carbohydrate-rich honeydew from hemipterans and in turn, provide them protection from enemies and sometimes transport them (reviewed by Mgocheki and Addison, 2009). A total of 10 species of ants were found to be associated with the vine mealybug, *Planococcus ficus*, the most abundant being *Crematogaster auberti*, *Iberoformica subrufa* and *P. pygmaea* (Gonçalves *et al*., 2014a).

Collembola are common in soil, leaf litter and other decaying organic matter, playing an important role in nutrient cycling and maintaining soil microstructure. Furthermore, they are alternative prey for generalist predators, in particular small spiders, thus enabling the increment of predator densities and so enhancing pest biological control (reviewed by Gonçalves *et al*., 2018a).

Oribatid mites are the world's most numerous arthropods living in soil; they are important soil decomposers by feeding on a variety of leaf litter material, including bacteria and yeast, algae, fungi and rotting wood (reviewed by Gonçalves *et al*., 2018b). Mesostigmatid and prostigmatid mites are predators, eating small invertebrates, bacteria, and fungi; some prostigmatids can live on other animals as parasites (reviewed by Gonçalves *et al*., 2018b). In Prostigmata, it is also frequent to find mites from Anystidae (Figure 2A) and Erythraeidae, respectively predating or parasitizing nymphs of Cicadellidae (Carlos, unpublished data).

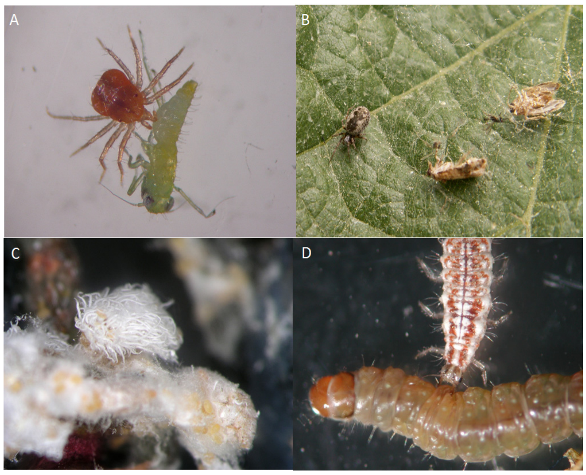

Figure 2. Predatory arthropods collected in the Douro Demarcated Region: Anystidae preying an *Empoasca vitis* nymph (A); *Nigma* sp. (Araneae: Dictynidae) preying adults of *Lobesia botrana* (B); larvae of *Scymnus* sp. (Coccinellidae) feeding on eggs and nymphs of *Planococcus ficus* (C); larva of *Chrysoperla carnea* sl. (Chrysopidae) preying a larvae of *L. botrana* (D). Authorship: C. Carlos/ ADVID (a, b, d); F. Gonçalves/ UTAD (c)

Artrópodes predadores observados na Região Demarcada do Douro: Anystidae a predar ninfa de Empoasca vitis (A); Nigma sp. (Araneae: Dictynidae) a predar adultos de Lobesia botrana (B); larva de Scymnus sp. (Coccinellidae) a predar ovos e ninfa de Planococcus ficus (C); larva de Chrysoperla carnea sl. (Chrysopidae) a predar uma lagarta de L. botrana (D). Autoria: C. Carlo/ ADVID (a, b, d); F. Gonçalves/ UTAD (c)

Empoasca vitis (the green leafhopper) and *Neoaliturus fenestratus* in Cicadellidae were very abundant species in vineyards. The green leafhopper is a polyphagous species which feeds on the phloem of plants; due to this feeding activity, leaf margins can become reddish or yellowish and then desiccate. Leaf symptoms are associated with physiological damage, which can lead to economic damage (i.e., yield losses and sugar content reduction of berries) when the infestation is high (reviewed by Tacoli *et al*., 2017). *Hyalesthes obsoletus* (Cixiidae), a vector of phytoplasma diseases “Bois noir disease” (Carlos, 2017) and *Philaenus spumarius* (Cercopidae) considered the main vector of the bacterium *Xylella fastidiosa*, were also recorded.

The Lepidopteran *Lobesia botrana* (European grapevine moth) was also very frequently observed, both in visual inspection of grape clusters or in traps.

This species is among the most economically important vineyard pests; damages are mainly caused by larval feeding on grape clusters, which renders them susceptible to *Botrytis cinerea*, leading to the development of primary and secondary rots at harvest (Ioriatti *et al*., 2011). During the harvest, other moths were sporadically observed infesting grape clusters, namely *Ephestia unicolorella woodiella* and *Cadra figulilella* (Carlos *et al*., 2013a).

Regarding Araneae from vegetation, the families that stood out were Dictynidae (e.g. *Nigma* sp. and *Dictyna* cf. *civica)*, Salticidae (e.g. *Icius subinermis, Salticus scenicus* and *Evarcha* sp.), Thomisidae (e.g. *Synema* sp. and *Xysticus* sp.), Oxyopidae (e.g. *Oxyopes* sp.), and Araneidae (e.g. *Mangora acalypha*) (Carlos, 2017). In the soil-surface, the most frequent were Araneae from the families Zodariidae (e.g. *Zodarion styliferum, Z. alacre*, and *Z. duriense*), Gnaphosidae (e.g. *Callilepis concolor, Zelotes fulvopilosus*, and *Haplodrassus dalmatensis*), Lycosidae (e.g. *Alopecosa albofasciata, Arctosa personata*, and *Pardosa proxima*), Thomisidae (e.g. *Ozyptila pauxilla* and *Xysticus bufo*), and Agelenidae (e.g. *Eratigena bucculenta* and *E. feminea*) (Gonçalves *et al*., 2017; Carlos et al., 2019). The members of the Araneae are important predators that feed primarily on insects (Wise, 1993). Although it is assumed that they are generalists feeding on a wide variety of prey types (Cardoso *et al*., 2011), some species are specialized in hunting a singular prey group (Pekár *et al*., 2012). For instance, spiders from Zodariidae feed exclusively on ants. Positive correlations between the abundance of ants and the abundance of ant-eating spiders were found (Gonçalves *et al*., 2017). Spider webs with cadavers of adult and immature cicadellids were commonly found, mainly *E. vitis*, and adults of *L. botrana* (Figure 2B). Also, immatures of the cicadellid *Scaphoideus titanus* (Gonçalves *et al*., 2014b) and adults of *L. botrana* (Carlos, unpublished data) were reported to be predated by *Dictyna* genera spiders.

In Carabidae, *Dromius meridionalis, Notiophilus* sp. and *Bembidion* sp. were frequently found in vegetation, while *Calathus fuscipes, Nebria brevicollis*, *Brachinus* sp. and *Microlestes* sp. were found in the ground. The majority of Carabids are generalist predators and potentially important natural enemies of pests; and because they react sensitively to human changes in habitat quality, they are considered important bioindicators (Kromp 1999).

Among Staphylinidae, *Quedius semiobscurus* and *Medon* sp. were frequently found in vegetation, while *Ocypus olens, Anotylus inustus*, and *Atheta coriaria* were found in the ground (Gonçalves, unpublished data). The majority of staphylinids are generalist predators; moreover, they are considered important bioindicators of the environmental status and particularly of human influence on ecosystems, namely of changes in management practices (Bohac, 1999).

In Coccinellidae, *Scymnus* sp. and *Rhyzobius* sp. were the most abundant genera observed (Carlos, 2017), although the seven-spot ladybird, *Coccinella septempunctata*, was often observed too. According to Daane *et al*. (2012), *Scymnus* sp. (Figure 2C) may be one of the most abundant mealybug predators in vineyards. Their larvae are mealybug mimics, exhibiting wax-like filaments similar to those of mealybugs, which allow them to forage without being noticed by defensive ants (reviewed by Daane *et al*., 2012).

Other predators were frequently captured in traps or observed by visual inspections. These include, among others, species from the families Miridae (e.g. *Malacocoris chlorizan*s and *Deraeocoris* sp.), Anthocoridae (e.g. *Anthocoris nemoralis* and *Orius* sp.), Nabidae (e.g. *Himacerus* sp.) (Goula *et al*., 2016; Carlos, 2017), Syrphidae (e.g. *Sphaerophoria scripta* and *Eupeodes corollae*) (Gonçalves *et al*., 2015a), and Chrysopidae (*Chrysoperla carnea* s.l.). Larvae of *C. carnea* s.l. were frequently found predating larvae of *L. botrana* (Figure 2D) (Carlos, unpublished data). Also, larvae of the Cecidomyiidae, *Dicrodiplosis* sp. were commonly observed in mealybug colonies feeding primarily on eggs and small nymphs (Gonçalves, unpublished data).

In the soil, the most important role of predators would consist of controlling the arthropods that spend part of their life span on the ground, such as *Noctua* sp., the vine weevil, *Otiorhynchus sulcatus*, and the overwintering pupae of *L. botrana*, or also those which use plants from ground cover as hosts, such as *Tetranychus urticae*, *Scaphoideus titanus* and *Philaenus spumarius*, which can be phytophagous or vectors of important vineyard diseases (reviewed by Gonçalves *et al*., 2018a). Nevertheless, some soil predators can climb up the crop canopy to search for their prey (Kendall, 2003). For instance, in Californian vineyards, certain spider species were found to move between the ground cover and the canopy, showing that spiders may link the food webs of the ground cover to the vineyard canopy (reviewed by Hoffmann *et al*., 2017). In apple orchards, ground spiders are mainly involved in the predation of emergent nymphs of codling moth during spring, while carabid beetles are involved in the predation of pupae during autumn (reviewed by Thiéry *et al*., 2018). These results could be extrapolated to vineyards, and by their abundance and diversity, those predators may be considered key predators in the natural control of *L. botrana* (reviewed by Thiéry *et al*., 2018).

Several families of parasitoids were captured in traps or observed by visual inspection, namely Aphelinidae, Braconidae, Chalcididae, Encyrtidae, Eulophidae, Ichneumonidae, Mymaridae, Platygastridae, and Pteromalidae (Carlos, 2017). These families include species which are important for the natural control of pests like *L. botrana*, *E. vitis*, and *P. ficus*. Thus, *Elachertus* sp. (Eulophidae) (Figure 3A and B), *Campoplex capitator* (Ichneumonidae), *Brachymeria tibialis* (Chalcididae), and *Dibrachys cavus* (Pteromalidae) were found to be important parasitoids of *L. botrana* (Carlos et al., 2013c; Carlos, 2017). On the other hand, egg parasitoids from the Mymaridae family (Figure 3C), in particular *Anagrus atomus*, are considered the most important natural enemies of *E. vitis* (Pavan and Picotti, 2009). Moreover, *Anagyrus* sp. nr. *pseudococci* (Encyrtidae) (Figure 3D) were frequently found parasitizing *P. ficus* (Sharma *et al*., 2018), and the females of this species, which are attracted to the sex pheromone of *P. ficus* (Franco *et al*. 2008), were observed in pheromone sticky traps used to monitor *P. ficus* males (Gonçalves *et al*., 2014c).

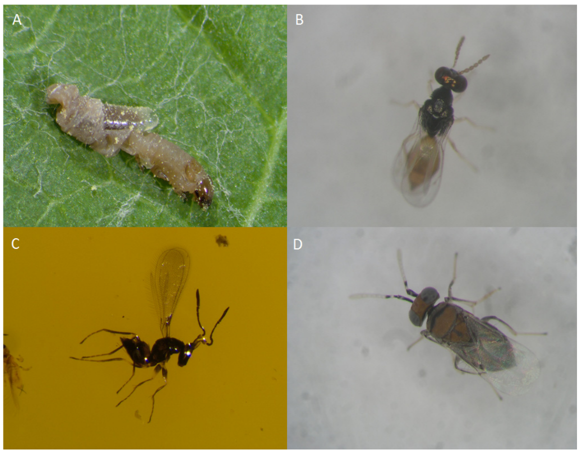

Figure 3. Arthropods parasitoids collected in the Douro Demarcated Region: *Elachertus* sp. (Eulophidae) parasitizing a larva of *Lobesia botrana* (A); adult of *Elachertus* sp. (B); adult of Mymaridae, an important parasitoid of *Empoasca vitis* (C); adult of *Anagyrus* sp. nr. *pseudococci* (Encyrtidae), an important parasitoid of *Planococcus ficus* (D). Authorship: F. Gonçalves/ UTAD

Artrópodes parasitóides observados na Região Demarcada do Douro: Elachertus sp. (Eulophidae) a parasitar uma lagarta de Lobesia botrana (A); adulto de Elachertus sp. (B); adulto de Mymaridae, um importante parasitóide de Empoasca vitis (C); adulto de Anagyrus sp. nr. pseudococci (Encyrtidae), um importante parasitóide de Planococcus ficus (D). Autoria: F. Gonçalves/ UTAD

HABITAT CONSERVATION AND MANIPULATION

The conservation and manipulation of habitats and the use of alternative farming practices can contribute to biodiversity conservation and enhancement. However, biodiversity by itself does not automatically translate into ecosystem services. For these services to be optimized, it is necessary to understand which biodiversity elements drive such ecosystem services (ELN-FAB, 2012). Based on this knowledge, the benefits to the ecosystem can be generated through a rational design of management strategies. These strategies may consist of maintaining or promoting the development of non-crop vegetation, such as field margins, forests, hedgerows, and other non-crop elements, or they may also imply adopting less invasive cultural practices (ELN-FAB, 2012).

Agricultural intensification through landscape simplification has negative effects on the provision of ecosystem services in agricultural landscapes such as Conservation Biological Control (CBC) (Rusch *et al*., 2016), which is an important service delivered by arthropods. CBC is a pest control strategy based on the manipulation of wild populations of natural enemies in order to enhance their impact on pests, and it involves diversifying agroecosystems so as to provide populations with habitat and food sources (Böller *et al*., 2004). Definitively, preserving and restoring semi-natural habitats emerges as a fundamental first step to maintain and enhance pest control services provided by natural enemies (Rusch *et al*., 2016). Thus, non-crop vegetation may provide habitat and overwintering sites, shelter, nectar, alternative prey/hosts, and pollen (SNAP) for predatory arthropods and parasitoids, which in turn can enhance CBC, thereby potentially reducing the need for pesticide use (Power, 2010). Moreover, perennial vegetation such as forests can regulate the capture, infiltration, retention and flow of water across the landscape (Power, 2010). In addition, it generally assures biodiversity conservation in agricultural areas (Wezel *et al*., 2014).

Furthermore, in the DDR, also a tourist landscape, with a part of the area declared as a World Heritage Site, the maintenance of these areas and the preservation of plant species with ornamental, landscape and conservative interest, is of special concern. This is the case of endemic species, which display a strong dependence on climatic conditions as a consequence of their limited distribution, and which due to these circumstances, are more subject to extinction. The endemic plant species which stand out in the DDR are: *Quercus* × *coutinhoi* among trees, *Cistus ladanifer* subsp. *ladanifer*, *Cytisus striatus*, *C. multiflorus*, *Erica umbellata*, *Lavandula stoechas*, *L. pedunculata* (Figure 4A), *Lonicera periclymenum* subsp. *Hispanica*, and *Halimium lasianthum* subsp. *alyssoides* among shrubs, *Dianthus lusitanus* (Figure 4B) and *Ortegia hispanica, Origanum virens, Thymus mastichina, Spergularia purpurea, Linaria aeruginea* (Figure 4C) and *Erysimum linifolium* (Figure 4D) among herbaceous vegetation. A list of species with agronomic, touristic and ethnobotanical interest is detailed in Carlos *et al*. (2013b).

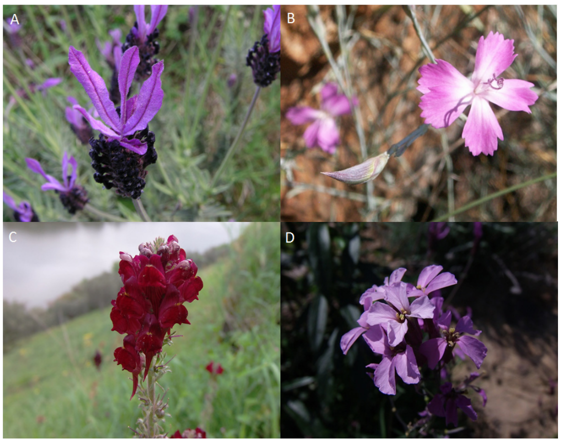

Figure 4. Endemic plant species of the *Iberian* Peninsula, observed in the Douro Demarcated Region: *Lavandula stoechas* (Lamiaceae) (A), *Dianthus lusitanus* (Caryophyllaceae) (B), *Linaria aeruginea* (Scrophulariaceae) (C), and *Erysimum linifolium* (Brassicaceae) (D). Authorship: C. Carlos/ ADVID (b); F. Gonçalves/ UTAD (a, c, d)

Plantas endémicas da Peninsula Ibérica, observadas na Região Demarcada do Douro: Lavandula stoechas (Lamiaceae) (A), Dianthus lusitanus (Caryophyllaceae) (B), Linaria aeruginea (Scrophulariaceae) (C) e Erysimum linifolium (Brassicaceae) (D). Autoria: C. Carlos/ ADVID (b); F. Gonçalves/ UTAD (a, c, d)

The impact of vineyards adjacent vegetation on arthropods

Vineyards adjacent vegetation in the DDR consists essentially of shrubland (mainly composed of *C. albidus*, *C. ladanifer* subsp. *ladanifer*, *C. salvifolius*, *C. multiflorus*, *Erica arborea*, *E. umbellata*, *Genista anglica*, *G. triacanthos*, *Halimium lasianthum*, *Juniperus oxycedrus*, *L. pedunculata*, *L. stoechas, Pistacia terebinthus*, *Rubus ulmifolius*, *Ulex minor*, and *Xolantha guttata*), woodlands (mainly composed of *Arbutus unedo*, *Pinus pinaster*, *Quercus* × *coutinhoi*, *Q. faginea*, *Q. pyrenaica*, and *Q. rotundifolia*), and groves (olive trees - *Olea europaea* - and almonds trees - *Prunus dulcis*) (Carlos, 2017; Gonçalves *et al*., 2017).

The plantation of shrubs in unproductive areas, like those between plots (Figure 5A) or along roadsides (Figure 5B), should be considered. Such plants do not interfere with the crop and provide necessary resources for natural enemies during the periods when the flowers of the crop or ground cover are not present, thus enabling to maintenance of high populations of those arthropods (Rodriguez-Saona *et al*., 2012). For this propose, there might be an interest in the plantation of *Viburnum tinus*, *C. albidus*, *C. ladanifer*, *C. salvifolius*, *L. stoechas*, *Lonicera* spp., and *T. mastichina*, which are plant species adapted to the DDR edaphic and climatic conditions.

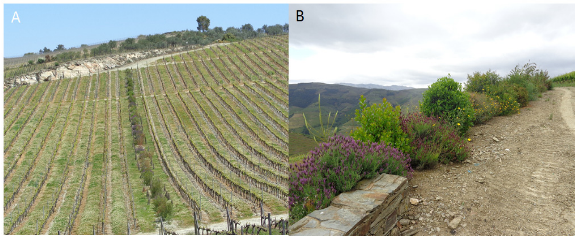

Figure 5. Examples of hedgerows installed in the Douro Demarcated Region: between plots of vineyards (A) or along roadsides (B). Authorship: C. Carlos/ ADVID

Exemplos de sebes instaladas na Região Demarcada do Douro: aproveitando áreas entre parcelas (A) e ao longo das estradas (B). Autoria: C. Carlos/ ADVID

The strawberry tree, *A. unedo*, is also considered an important species in the DDR vineyards from a CBC point of view; it was found to host several groups of insects known to include important natural enemies of vineyards pests, as among which: Coccinellidae, Syrphidae, Chrysopidae, Ichneumonoidea, Chalcidoidea, and Heteroptera; this is probably due to the presence of abundant honeydew excreted by the aphid *Wahlgreniella arbuti*, from which those individuals can obtain additional food to supplement their diet (Gonzalez *et al*., 2015). *A. unedo* also hosts the two-tailed Pasha, *Charaxes jasius* (Gonzalez *et al*., 2015), a beautiful butterfly confined to the Mediterranean region which although not currently threatened, has been predicted by models to be very badly affected by future climate change (Swaay *et al*., 2010).

The Gryllidae *S. lusitanica* is an endemic species of the Iberian Peninsula (Figure 1D) that is sensitive to changes in its habitat. It occurs in association with *C. ladanifer*, *Lavandula* spp. and *E. arborea*, with the first two species being very common in the farm where this specimen was observed (Gonçalves *et al*., 2018a).

Results from the DDR showed that the abundance of both soil-surface predators and omnivores was higher in adjacent vegetation than in vineyards, while that of detritivores was higher inside the vineyards (Carlos et al., 2019). In addition, it was found that during spring, the abundance of predators in vineyards decreased with the increasing distance from adjacent vegetation, pointing to the importance of these habitats as refuge and hibernation sites, from where predators colonize the vineyards (Gonçalves *et al*., 2018a). The abundance of detritivores (mainly Collembola) was relatively low in soils from adjacent vegetation and near the vineyard borders, probably due to the higher abundance of generalist predators in these places, which may also feed on them (Carlos et al., 2019). Concerning aerial arthropods, although a high abundance and richness of several beneficial groups (i.e. Coccinellidae, Araneae, and Hymenoptera parasitoids) was found in adjacent vegetation, the positive impact of these habitats on nearby vineyards was only found for Coccinellidae (Carlos, 2017).

SOIL MANAGEMENT PRACTICES

Soil management practices such as no or reduced tillage and non-use of herbicides can provide agricultural benefits while minimizing the negative effects of agriculture on soil biota. Moreover, conserving the soil biological potential can enhance or maintain soil organic matter content and therefore, contribute to long-term soil preservation (reviewed by Bender *et al*., 2016). Such conservation practices are often most successful in combination with other measures such as cover crops, mulches (reviewed by Bender *et al*., 2016), and soil amendment applications.

The impact of ground cover on arthropods

The ground cover of horizontal alleys and embankments of vine terraces is advisable, since it was found to have numerous benefits, such as: (a) increasing water infiltration; (b) protecting the soil surface from the impact of raindrops, (c) facilitating the formation and stabilization of soil aggregates; (d) reducing soil erosion by enhancing the soil organic matter and microbiological function (revision of Prosdocimi *et al*., 2016); e) incrementing both animal and plant biodiversity; and f) promoting the activity of natural enemies and the consequent biological control of pests.

Ground cover manipulation can benefit the communities of pests' natural enemies and promote biological control by providing these communities with food in the form of floral resources. This was shown by the increment of parasitoids longevity and fecundity and the consequent increase in parasitism rates observed in tortricids (reviewed by Thiéry *et al*., 2018).

When opting for a ground cover, preference should be given to a spontaneous colonization by the local flora (Figure 6A) (Böller *et al*., 2004), which is adapted to the local environment, may require little or no maintenance, and is admissible to better benefit the native arthropods and pest suppression (reviewed by Daane *et al*., 2018). Plant species that naturally occur on the ground cover of the DDR vineyards predominantly include: *Andryala integrifolia*, *Bromus* spp., *Coleostephus myconis*, *Convolvulus arvensis*, *Cynodon dactylon*, *Echium plantagineum*, *Lolium rigidum*, *Medicago* spp., *Ornithopus* spp., *Silene gallica*, *Solanum* spp., *Sonchus* spp., *Trifolium* spp. and *Vulpia* spp.. A list of plant species valuable for fostering vineyard pests' natural enemies was documented by Carlos *et al*. (2013b). In the case of sown ground cover with plants of different species and families (Figure 6B), different flowering periods and root systems should be evaluated so that full benefit can be taken of this management practice (Garcia *et al*., 2018).

Figure 6. Examples of natural (A) and sown ground covers with a mixture of Fabaceae and Poaceae species (B), and ground cover mowed in alternated rows (C). Authorship: F. Gonçalves/ UTAD

Exemplos de coberto vegetal natural (A) e semeado com espécies de Fabaceae e Poaceae (B); e coberto vegetal cortado, em linhas alternadas (C). Autoria: F. Gonçalves/ UTAD

Ideally, ground cover should be mowed after flowering (when pollen and nectar are provided) (Figure 7) and seed production so as to enable self-seeding. In the DDR conditions (precipitation during the growing season April-September is between 189 and 326 mm, depending on the location) (Jones and Alves, 2012), ground cover generally dries from late May onwards. In rainy years, the ground cover could be mowed in mid-spring and in alternate rows, if possible, so that continuous habitat availability is provided to natural enemies as they move between rows (Figure 6C). After mowing, the cut vegetation should be left on the soil surface to act as mulching, namely because in addition to a number of other benefits, mulching was shown to enhance the abundance and/or diversity of several groups of vineyard pests' natural enemies without increasing the abundance of the pests (Thomson and Hoffmann, 2007; Bruggisser *et al*., 2010).

In the DDR, the vegetation present in the horizontal alleys and embankments of the terraces was found to have particularly benefitted Araneae (in the predators) and Hymenoptera parasitoids (Carlos, 2017). The abundance and richness of predators in the soil (mainly Araneae and Carabidae) was positively correlated with the percentage of ground cover and the richness of plants (Gonçalves *et al*., 2018a).

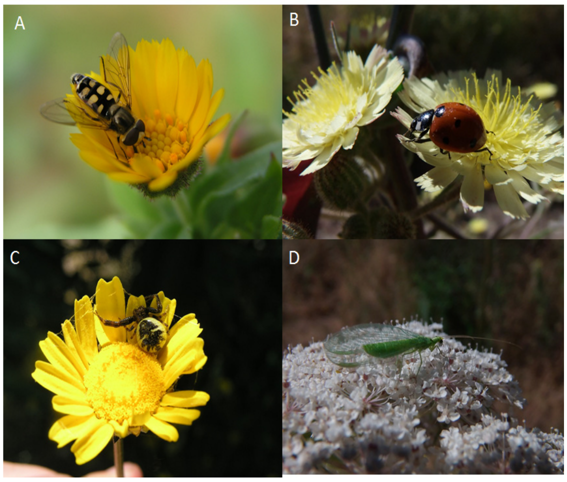

Figure 7. Predators frequently found in vineyard ecosystems; *Eupeodes corollae* (Syrphidae) (A), *Coccinella septempunctata* (Coccinellidae) (B) *Synema* cf. *globosum* (Araneae) in Asteraceae, and *Chrysoperla* sp. in Apiaceae (D). Authorship: F. Gonçalves/ UTAD

Predadores frequentemente observados no ecossistema vitícola: Eupeodes corollae (Syrphidae) (A), Coccinella septempunctata. Autoria: F. Gonçalves/ UTAD

On the other hand, in a study aimed at comparing the effect of two types of ground cover (natural vegetation and sown vegetation) and soil tillage on both soil-surface and soil-living arthropods, it was found that the abundance of soil-surface predators was higher in both soils with ground cover than in the tillage soil; moreover, the abundance and richness of soil-living arthropods was also higher in both soils with ground cover (Nunes *et al*., 2015; Gonçalves *et al*., *in press*). Such results show that using soil tillage in vineyards, even when superficial, may be unfavourable to soil arthropods.

Soil amendments application

Vineyard management is considered one of the land-uses most prone to causing very low soil organic matter content, which impoverishes the soil agronomic potential (López-Piñero *et al*., 2013) by negatively affecting its quality and functioning. Organic amendments offer many opportunities for improving soil properties, both directly through their intrinsic properties, and indirectly, by modifying the soil physical, biological and chemical properties (Larney and Angers, 2012). The use of composts from winery wastes as soil amendments in vineyards, namely from winery sludge and grape stalks, is of great interest due to the acknowledgement of their high agronomic value and because in this way, they can be reintroduced into the production system, thereby closing the residual material cycle (Bertran *et al*., 2004).

The applications of biochar to soil vineyards to improve soil properties and plant performance have also received increasing attention. Thus, adding biochar to the soil apparently improves the soil water holding capacity, water infiltration, soil water availability, nutrient retention, hydraulic conductivity, soil aeration (reviewed by Schmidt *et al*., 2014), the stabilization of soil organic matter, and soil carbon sequestration (Nair *et al*., 2017). Other effects of biochar could be an increase in microbial activity, shifts in microbial diversity, an increase in electrical conductivity and immobilization of contaminants (such as heavy metals) or pesticides (reviewed by Schmidt *et al*., 2014).

Biochar plus compost mixtures are becoming popular, especially when biochar is mixed with biomass before composting, and this combination seems to be a promising source of amendment and an interesting alternative to inorganic fertilizers (Nair *et al*., 2017). It seems that during composting, oxygen-containing functional groups are produced, which leads to an increase in nutrient retention (reviewed by Nair *et al*., 2017), the microbial colonization is stimulated, and possible noxious pyrogenic substances are degraded (reviewed by Schmidt *et al*., 2014).

A field trial has been carried out in the DDR since 2016 in order to evaluate the effect on the abundance and richness of soil-surface arthropods of three soil amendments (1- compost of winery wastes (sludge mixed with grape stalks) (Figure 8A); 2 – compost-biochar (mixed after the composting process); and 3 - biochar alone (Figure 8B)) in comparison to an unamended treatment. Results have shown that the abundance of predators, particularly of Carabidae plus Staphylinidae and Opiliones, was higher in compost and biochar-compost treatments than in either the unamended treatment or the biochar alone treatment (Gonçalves *et al*., 2018c).

Figure 8. Application of soil amendments in a Douro Demarcated Region vineyard: compost made up of winery wastes (A) and biochar (B). Authorship: F. Gonçalves/ UTAD

Aplicação de corretivos numa vinha da Região Demarcada do Douro: compostado elaborado com resíduos provenientes da adega (A) e biochar (B). Autoria: F. Gonçalves/ UTAD

CONCLUDING REMARKS

As stated by Lucchi and Benelli (2018), the sharing of needs and knowledge promotes Integrated Pest Management. In fact, it is important that the knowledge generated by researchers reaches the main stakeholders (e.g. wine growers, technicians, policymakers and other researchers). The main objectives of the present work regarding the DDR viticulture were: a) to provide information on biodiversity and ecosystem services provided by the region's vineyard agroecosystem; and (b) to encourage the adoption of practices capable of increasing the provision of such services, namely those that can benefit vine growers directly. Ultimately, the purpose is to manage the ecosystem in order to increase the required ecosystem services without impairing farmers' economic return (Garcia *et al*., 2018). Although this review only focuses on arthropods, the selection of the management practices to be adopted should also consider other variables such as plant nutrition, vigour, yield and fruit quality, water infiltration and competition, greenhouse gas emissions, and soil fertility.

In order to achieve the abovementioned objectives, several technical documents were drawn up which were and disseminated to end users, namely wine growers (e.g. Carlos *et al*., 2013b; Gonçalves *et al*., 2013a,c; 2018b), along with a photography exhibition (Agrofood3.0, 2015) and short documentaries (Agrofood3.0, 2014a, b; ADVID, 2014; Santos, 2014). A web application was also developed to provide detailed and updated information about arthropods associated with the DDR vineyards (Reis, 2018; Reis *et al*., 2018). The application is available at www.artropodesvinha.utad.pt, and has useful information to train wine growers and technicians to recognize and monitor pests and natural enemies' populations.

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