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The organic vineyard as a balanced ecosystem: Improved organic grape management and impacts on wine quality

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ABSTRACT

Worldwide interest for organic farming increased significantly since the last decade. Wine makes no exception to this trend, as consumer demand for organic wines and environmental friendly viticulture practices increases. Organic wine production aims at producing high quality grapes and wines while minimizing the use of inputs, both in the vineyard and the winery. Its success lies in an approach that takes advantage of the biodiversity to maintain a balance between resource availability, living organisms and productivity in the vineyard, while maintaining pest and disease at the lowest level. In this review, we will present management practices for successful grape production under organic management, including methods for disease and pest prevention, and treatments in the vineyard. Then, we will review the impact of organic grape management on the quality of organic wine.

1. Introduction

Conventional viticulture is among the most pesticide-consuming agricultural systems (Aubertot et al., 2005). For example, grape production in France occupies less than 3% of the total area devoted to agriculture and consumes nearly 20% of total pesticides (Aubertot et al., 2005; Delière et al., 2014). In Italy, more than 200 different pesticides are registered for grapevine (Cabras and Conte, 2001). The intensive use of pesticides triggers the build-up of pest systemic resistance (Leroux et al., 2002; Savocchia et al., 2004) and negatively impacts non-targeted organisms including fauna, plants, and microbiota (Hildebrandt et al., 2008; Komárek et al., 2010; Nash et al., 2010). In this context, the reduction of pesticide in viticulture and higher deployment of organic viticulture become highly valuable.

From 2002 to 2013, areas devoted to organic grape production significantly increased (Table 1). Representing 4.6% of the total grape production, in a total of 310 000 ha, the three most important producing countries are Spain, France and Italy (Willer and Lernoud, 2015). Although Europe owns 90% of the total cultivated area, organic grape production recently expanded in other countries such as China and Turkey (Willer and Lernoud, 2015). Despite these significant expansions, several factors may have slowed down the progression of organic viticulture, including unreliable yields, issues with pest management, and the need to educate consumers in organic products (Willer et al., 2008). Consumers either have a negative perception of organic wines quality, or are not willing to pay higher cost generally attached to these wines (Iordachescu et al., 2009; Ogbeide, 2015; Rojas-Méndez et al., 2015). In addition, crop yield may be reduced by 8–16% compared to conventional grapevines (Bayramoglu and Gundogmus, 2008; Guesmi et al., 2012). Therefore, the challenge of organic wine production is significant: organic growers and winemakers are expected to produce wines using pesticides and inputs chosen from an approved list while maintaining the high quality requested by consumers.

Success in organic viticulture is mainly based on implementing a production system that minimizes the incidence of disease and pest and consequently reduce the use of pesticides such as copper-based fungicides, without compromising crop productivity (Sivčev et al., 2010). A successful approach is to consider the vineyard as an ecosystem where every resource is optimized to maintain a

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Table 1
Worldwide progression of areas devoted to organic grape production 2002–2013 and conventional grape production (2012–2013).

Country	Area under organic production (ha)												Total cultivated area (ha)
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2012–2013
Argentina											5 359	4 139	221 000
Austria	1 114	1 536	1 657	1 791	1 766	2 477	2 773	3 218	3 863	4 178	4 259	4 414	43 700
Canada							112	129			262	347	11650
Chile											4592	3 595	205 000
China											2 000	19 174	570 000
France	15 013	16 259	16 428	18 133	18 808	22 509	27 869	39 146	50 268	61 056	64 801	64 610	800 000
Germany						3 500	4 400	4 700	5 200	6 900	7 400	7 100	100 000
Greece	2 599	3 168	3 303	3 955	4 603	4 561	5 024	4 875	5 001	4 807	4 997	4 718	110 000
Italy	37 379	31 709	31 170	33 885	37 694	36 684	40 480	43 614	52 273	52 812	57 347	67 937	769 000
Portugal	575	839	1002	1 240	1 178	2 021	2 028	1 804	2 667	2 523	2 523	2 523	239 000
Spain	16 038	16 453	14 928	15 991	16 832	17 189	30 856	53 959	57 232	79 016	81 262	83 932	1 018 000
Turkey											6 571	8 418	517 000
United States	5 088			9 226			11 448			15 646	15 647	15 647	394 000
Total	77 806	69 964	68 488	84 221	80 881	88 941	124 990	151 445	176 504	226 938	257 020	286 554	4 998 350

Sources: (European Commission, 2013; Karlsson, 2014; Macey, 2010, 2011, 2012; USDA, 2015a; Willer, 2008; Willer and Yussefi, 2006; Willer and Lernoud, 2014, 2015).

rich biodiversity contributing to decrease pest and disease pressure (Thies and Tscharntke, 1999). Such crop production systems largely differ from conventional production and may therefore have several impacts on wine composition and quality, possibly justifying the high price of organic wines (Rojas-Méndez et al., 2015). In this review, we will present how an approach based on biodiversity can contribute to preserve the organic vineyard ecosystem for successful organic grape production, present certain techniques and products used in organic growing, and report recent studies on the impact of organic viticulture on wine quality.

2. The organic vineyard as a balanced ecosystem

A balanced ecosystem is defined as a diversity of organisms, such as fauna, plants and microorganisms, living in complementarity in a competing system (Begon et al., 1996). In natural ecosystems, a rich biodiversity prevents the domination of a single species over the others (Thies and Tscharntke, 1999). In contrast, the vineyard is a monoculture that artificially favors a perennial species (e.g. grapevine) over the others, a balance that is maintained through the use of synthetic pesticides in conventional viticulture. Conversely, organic viticulture aims at reducing the use of approved pesticides by adopting different practices that promotes an adequate biodiversity within the production system.

Increasing the presence of beneficial organisms that maintain enemies at under control contributes to preserve the balance between the main crop and the other organisms (Thies and Tscharntke, 1999). The success of this approach is based on three key elements: (i) manage resources availability by improving soil structure, and controlling competition and crop attractiveness; (ii) improve arthropod diversity to constraint grapevine enemies and (iii) prevent diseases using optimal canopy management practices (Rombourgh, 2002).

2.1. Resources management

2.1.1. Maintain or improve soil structure

Soil is considered as an interactive system in which its structure, flora, fauna, and organic matter are strongly interrelated (Coleman et al., 1992). In organic vineyard, cultural practices, such as mulches, cover crops, organic enrichments and cultivation, are recognized to modulate soil structure and composition. Mulches help to rebuild the soil food web after the vine plantation (Rombourgh, 2002).

When resources like water are not limited, cover crops (CC) may provide additional organic matter and significantly contribute to improve soil quality (Adams, 2011; Ingels et al., 2005; McGourty and Reganold, 2005; Wheaton et al., 2008). Under organic management, CC and organic matter inputs generally have a positive impact on earthworms by increasing their abundance and biomass (Pérès et al., 1998). However, Coll et al. (2011) showed that the density and biomass of earthworm decreased in organic vineyard without organic matter inputs, while the biomass of soil microorganisms and the nematofauna were found to increase. CC are also known to increase microbial communities in cover cropped vineyards when compared to disk control, but the CC species does not impact the composition of the microbial community (Ingels et al., 2005).

2.1.2. Control competition: weeds, cover crops and grapevine

Weeds are plant species showing excessive growth and high adaptation to their growing environment. Unlike CC, they are aggressive, hardly manageable, and compromise vineyard productivity by competing with the vines (Wisler and Norris, 2005). The use of synthetic herbicides is prohibited in organic viticulture. Therefore, mechanical removal remains the primary option to control weed growth under rows, whereas CC are a proper option between rows (Pimentel et al., 1992; Sanguankeo et al., 2009). Early establishment of aggressive CC species, such as wheat and rye, or use of spring-planted plots, are the best strategies to decrease weed growth, biomass and density, without negative impacts on vine (Bordelon and Weller, 1997; Krohn and Ferree, 2005). Some CC species are better competitor (e.g. rye, wheat, barley, oats) than other (e.g. vetch) while others use allopathic effects (e.g. rye), so their potential for weed competition and suppression varies (Bordelon and Weller, 1997; Putman et al., 1986).

Competition for water and mineral resources has a direct impact on vine vigor, even when this competition comes from CC rather than weeds. In fact, lower pruning weights and shoot length, fewer lateral shoots and higher canopy openness have been observed in cover cropped vineyards (Ingels et al., 2005; Krohn and Ferree, 2005; Tesic et al., 2007). When resources are not limited (e.g., fertile soil, high water availability), such competition may improve vine balance by reducing excessive vigor and potentially improve crop quality without significant impact on yield (Giese et al., 2015; Ingels et al., 2005; Sweet and Schreiner, 2010; Wheeler et al., 2005). In contrast, long-term cover cropping is restricted in areas where water availability is limited (Guerra and Steenwerth, 2012).

Success with CC lies in proper selection of species and management methods to maximize the benefits and reduce potential problems (Guerra and Steenwerth, 2012; Ingels et al., 2005, 1998). Indeed, species such a clover, rye, ryegrass and fescue have been largely tested in viticulture and prove to be efficient in many countries (Guerra and Steenwerth, 2012). Yet, other factors may affect their impact in the organic vineyard such as vine age, initial status of soil nutrient and water capacity, and the proportion of CC within the growing area. When permanent cover cropping is used, a balance is usually reached after 4–5 years and their impacts on vine decrease (Sweet and Schreiner, 2010).

2.1.3. Implement cultural methods

Cultural control aims at making the crop less attractive to pests (Bostanian et al., 2012). Several approaches are used in perennial crops: use of resistant varieties and/or rootstocks (see Pedneault and Provost, 2016 for a review on fungus-resistant grapevine varieties), sanitation by removal of residuals, modification of harvest dates, implementation and/or conservation of trap plants, modulation of irrigation and fertilization schedules (Mills and Daane, 2005; Zehnder et al., 2007). In viticulture, the first significant practice used to reduce the occurrence of an aggressive pest was the grafting of *V. vinifera* varieties on North American *Vitis* spp. rootstocks showing high resistance to *Phylloxera* (Gale, 2003). This practice has been the main control against this pest for nearly 150 years, and new rootstocks continue to be bred to constrain the resistance (Korosi et al., 2003).

Optimal selection of grape varieties is advantageous to successfully control fungal diseases (Pedneault and Provost, 2016). Grape varieties may also contribute to control insect pests by enhancing the presence of predators in a variety-dependent manner. For example, Peverieri et al. (2009) evaluated the diversity and abundance of predacious mites in four vine varieties grown under three different managements (organic, conventional and untreated vineyard). Their results showed that the predatory mites *Kampimodromus aberrans* (Oudemans) and *Typhlodromus exhilaratus* (Ragusa) preferred the Verdicchio variety, whereas *Typhlodromus pyri* (Scheuten) and *Amblyseius andersoni* (Chant) were mostly found on Nero d'Avola grapes. In addition, the abundance of predatory mites was higher in the organic and untreated vineyards compared to the conventional vineyards. In other studies, grapevine variety was found to affect the fitness and the occurrence of the prey *Lobesia botrana*, including female and larval performance, female fecundity, and distribution pattern (Moreau et al., 2006; Sharon et al., 2009).

Considering the organic vineyard as an ecosystem is a key factor to optimize cultural control methods. Operations such as soil tillage and use of mulches may contribute to enhance the insect pest control by favoring the activity of beneficial microorganisms, modulating the dispersion and abundance of pests and increasing occurrence and diversity of natural enemies (Lotter et al., 1999; Powell et al., 2007; Sharley et al., 2008). Implementing optimal irrigation schedule may affect vine vigor and consequently equally modulate pest and predatory populations (Daane and Williams, 2003; Stavrinides et al., 2010). Vineyard sanitation, such as cutting wild grapevine and removing clusters and pruning woods left behind, is another way to reduce pests in the organic vineyard (Jenkins and Isaacs, 2007; Mills and Daane, 2005).

2.2. Improve arthropods biodiversity to constraint grapevine enemies

Several pests are detrimental to grapevine productivity and growth, including grape berry moth (*Paralobesia viteana* Clemens), grape leafhopper (*Erythroneura comes* Say), Japanese beetle (*Popillia japonica* Newman), grape phylloxera (*Daktulosphaira vitifoliae*), and mites (Bostanian et al., 2012). Conversely, avoiding the use of pesticides improves the diversity and the occurrence of arthropods in the organic vineyard. Methods that provide food or shelter for beneficial arthropods such as insects, mites, and spiders increase their biodiversity and further increase the rates of parasitism and predation against pests (Nicholls et al., 2000; Costello and Daane, 2003; Jonsson et al., 2010; Sanguankeo and León, 2011).

The composition of the local food web, the extent to which suitable and/or limited resources are available to the target's natural enemies, and food plants selection may be significantly improved with selected CC, but may also impact their efficiency at reducing the occurrence of pests (Begum et al., 2006; Jonsson et al., 2010; Guerra and Steenwerth, 2012). In organic vineyards from New Zealand, the presence of buckwheat and alyssum increased the fecundity and the longevity of a leafroller parasitoid, but the impact on the density of leafrollers remained unclear (Berndt et al., 2006; Scarratt, 2005). Another study showed that the presence of diversified flowering CC improved the parasitism of leafhopper eggs compared to the absence of CC (Nicholls et al., 2000). Similarly, the presence of flowers contributed to increase the population and diversity of predators, with consequent reduction of both leafhopper and thrips populations (Nicholls et al., 2000). Spiders were also found to reduce leafhopper populations under cover cropping, with the observation that mowing CC often triggered predators migration from CC to adjacent vines therefore improving their efficiency (Hanna et al., 2003). Another study carried out under organic management showed that reducing vine vigor through competition with CC efficiently reduced grapevine attractiveness for pests like leafhopper and European grapevine moth (Costello and Daane, 2003; Serra et al., 2006).

2.3. Canopy management to minimize diseases

Fungal diseases, including downy mildew (*Plasmopara viticola*), powdery mildew (*Uncinula necator*), anthracnose (*Elsinoe ampelina*), grey mold (*Botrytis cinerea*), and black rot (*Guignardia bedwelli*) are among the most significant issues in viticulture (Avenard et al., 2003; Reynier, 2012). Fungal diseases affect vegetative parts and reduce the photosynthetic capacity of the vine with the consequence that the plant is weaker, less hardy and less fruitful. On grapes, fungal infestation may cause significant loss in yield and affect quality (Avenard et al., 2003; Cilindre et al., 2007). In organic viticulture, fungal diseases command the use of inputs such as copper- and sulfur-based fungicides whose use should be minimized and accurately calculated (Rombourgh, 2002; Komárek et al., 2010). Therefore, maintaining disease occurrence at the lowest level is mandatory in organic grape production.

The occurrence of fungal disease as well as their future management is partly determined at vineyard implementation: site and grape varieties selection, row orientation, and eventually, selection and use of CC are of importance (Rombourgh, 2002; Avenard et al., 2003; Pedneault and Provost, 2016). Then, appropriate canopy architecture practices, such as the selection of the training system, trimming, pruning and leaf thinning, contribute to reduce the occurrence of fungal diseases (Rombourgh, 2002). Rootstock selection may equally impact disease occurrence by modifying grapevine vigor and canopy comptacness (Table 2; Ferreira and Marais, 1987; Koblet et al., 1994).

At the ground level, CC may contribute to lower the incidence of fungal diseases by increasing canopy openness and improve subcanopy aeration and temperature (Reynolds and Vanden Heuvel, 2009; Jacometti et al., 2010; Keller et al., 2015). Indeed, some studies demonstrated that CC may reduce soil water content and nutrients, resulting in lower number of leaf layer, reduced number of internal clusters and leaves, and higher gaps in the canopy (Guerra and Steenwerth 2012; Morlat and Jacquet, 2003; Tesic et al., 2007).

2.3.1. Training system

One of the objectives of grapevine training is to arrange perennial wood and canes to optimize leaf area exposition, to manage

Table 2
Impact of cultural practices on disease infections and on factors affecting disease occurrence.

Cultural practice	Grape variety	Impact on diseases	Factor affecting disease occurrence	Refs.
leaf removal	Emperor, Thompson Seedless		LR increased evaporation potential; wind speed and RH had the greater impact on BOT	Thomas et al. (1988)
	Zinfandel, Chenin blanc	LR reduced BOT	interaction between wind and RH reduced BOT; LR increased wind speed and evaporation potential	English et al. (1989)
	Barbera, Carignane, Chardonnay, Zinfandel, Thompson Seedless	LR reduced the population of *Penicillium*, BOT and *Aspergillus*	LR caused unfavorable conditions for the development of conidia and increased conidia destruction by ultraviolet radiation or desiccation	Duncan et al. (1995)
leaf removal and fungicide	Chardonnay	LR reduced PM; combination of LR and fungicide resulted in similar disease levels compared to conventional vineyard	LR favored the presence of fungicides on berries	Chellemi and Marois (1992)
rootstock	Pinot noir	101-14 Mgt presented higher diseases rates compared to 3309C	101-14 Mgt produced a higher number of berries and cluster	Koblet et al. (1994)
rootstock and pruning	Chenin blanc	rootstock Jacquez and 99 Richter reduced BOT; combinations of cane pruning with 99 Richter and 101-14 Mgt had positive impact on BOT control	rootstock Jacquez and 99 Richter reduced vine growth and cluster compactness	Ferreira and Marais (1987)
training system	Cabernet Sauvignon	reduced occurrence of DM on leave and BOT bunch rot with VSP compared to YT		Bern et al. (2015)
	Sangiovese	reduced occurrence of BOT with SAYM compared to VSP		Palliotti (2012)
	Chenin blanc, Zinfandel	XARM presented 47% more BOT	better penetration of wind and solar radiation with TWV	Savage and Sall (1982) Savage and Sall (1984)
	Chardonnay, Cabernet Sauvignon	free-positioned, topped vines reduced PM on berries and clusters compared to VSP	better air movement and sunlight with free-positioned vines	Zahavi et al. (2001) Zahavi and Reuveni (2012)
		Guyot increased BOT	poor air movement in high trained vines increased leaf temperature and lowered wind speed	Draganov and Draganov (1976)
	Cabernet Sauvignon		presence of injuries increased *Eutypa*	Lake et al. (1996)
	Chardonnay	UK and UK/MWC lowered the occurrence and severity of BOT compared to MWC	UK and UK/MWC reduced cluster compactness	Zabadal and Dittmer (1998)
training system and leaf removal	Chardonnay	VSP reduced PM development compared to UK; LR reduced the occurrence of PM; LR at berry set reduced PM; irrigation increased PM	reduction of shade and higher sunlight penetration reduced disease in VSP; irrigation increased shoot density	Austin (2010) Austin and Wilcox (2011)
training system and pruning	Concord	UK and TWC along with hand-pruning reduced the occurrence of *Phomopsis*	hedging was realized with mechanical cutting bars leaving amount of debris containing disease inoculum	Pscheidt and Pearson (1989)
Shoot topping	Pinot Gris and Riesling	late shoot topping delayed the moment when 5% disease severity of BOT was noted up to eleven days	late shoot topping reduced cluster compactness	Molitor et al. (2015)
Cluster division	Pinot Gris and Riesling	all postbloom cluster division treatments reduced BOT severity	cluster division reduced cluster compactness, and impacts on cluster structure are more pronounced with later treatments	Molitor et al. (2012)

[2] LR = leaf removal; RH = relative humidity; DM = downy mildew; PM = powdery mildew; BOT = *Botrytis*; training system: YT = Y-trellis; UK = Umbrella Kniffin; TWC = Topwire Cordon; SAYM = Y-shaped training system trained to an inclined shoot-positioned trellis; XARM = cross arm trellis; TWV = two wire vertical

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yield, and control diseases (Reynolds and Vanden Heuvel, 2009). By modifying the architecture of the canopy, the training system may modulate the intensity of epidemics by modifying the interception of fungal inoculum, by triggering microclimatic conditions favoring or disfavoring disease development, and by changing the dynamics of tissue receptivity (Tivoli et al., 2013). Canopy structures likely to decrease fungal infection will provide higher levels of air and ultraviolet radiation penetration under canopy, as well as lower and shorter wetness intervals (Table 2; Smart, 1985; Reynolds and Vanden Heuvel, 2009; Jacometti et al., 2010; Austin et al., 2011; Keller et al., 2015). For instance, VSP training reduced the occurrence of leaf downy mildew and botrytis bunch rot in Cabernet Sauvignon grapevine compared to grapevine trained as Y-trellis system (Table 2; Bern et al., 2015). Conversely, the occurrence of powdery mildew was reduced on berries and clusters of free-positioned, topped Chardonnay and Cabernet sauvignon vines compared to vertical shoot positioned vines (Table 2, Zahavi et al., 2001; Zahavi and Reuveni, 2012).

The impact of the training system on fungal diseases varies according to seasonal climatic conditions: under low disease pressure, the training system may significantly reduce the occurrence of disease infections, but under high pressure, its impact is considerably reduced (Zahavi et al., 2001; Austin and Wilcox, 2011; Bern et al., 2015). Some examples of the impact of canopy management practices on fungal diseases are shown in Table 2.

2.3.2. *Leaf removal*

Leaf removal (LR) is a technique used to improve airflow throughout the canopy and increase cluster exposure to sun (Elmer and Michailides, 2007; Reynier, 2012). LR has a direct impact on the quality of grapes and wines by primarily reducing the incidence of major diseases such as grey mold, powdery mildew and downy mildew (Reynolds, 2008; Jacometti et al., 2010; Verdenal et al., 2013). Trimming the fruit zone increases the temperature, lowers wetness and relative humidity, and increases wind speed around the cluster, therefore resulting in unfavorable conditions for the germination of fungal spores (i.e. *Botrytis*) (Guidoni et al., 2008; Tardaguila et al., 2010). In California, LR reduced by 62% the incidence of sour rot on untreated Carignane berries by causing unfavorable conditions for conidial germination (i.e., low humidity around clusters, higher exposure to sunlight) (Duncan et al., 1995). When pesticides are needed, LR enhances pesticide penetration in grapevine canopy, resulting in an increased efficiency and subsequent reduction in the frequency of pesticide applications (Chellemi and Marois, 1992; Ferree et al., 2003).

LR improves the thickness of physical barriers such as epicuticular wax and cuticle in exposed berries (Percival et al., 1993). Cuticle is the first barrier against berry diseases. Epicuticular wax may prevent fungal infection but its efficiency decrease as berries mature, increasing crop susceptibility to *Botrytis* (Rosenquist and Morrison, 1989; Commentil et al., 1997). LR may also contribute to enhance the biosynthesis of natural defense compounds such as phytoalexins by increasing cluster exposure to UV light (Langcake, 1981).

The timing of LR impacts grapevines and berries in different ways when performed before fruit set, LR can negatively affect grapevine performance, while LR late in veraison can lead to higher risks of scalding berries (Bergqvist et al., 2001; Spayd et al., 2002; Verdenal et al., 2013). Best results may be expected on the control of *Botrytis* when LR is performed at fruit set (bunch closure).

The use of LR should be rationalized according to weather conditions. Under unfavorable conditions (e.g., wet season), LR can improve health and quality of berries whereas it can lead to sunburn damages when conditions are dry and hot (Bergqvist et al., 2001; Spayd et al., 2002; Guidoni et al., 2008). In general, the impacts of LR on disease incidence are higher in temperate regions compared to hot and dry areas (Ferree et al., 2003; Tardaguila et al., 2010; Austin and Wilcox, 2011).

2.3.3. *Reduce cluster compactness*

High cluster compactness has a significant impact on berry susceptibility to *Botrytis* bunch rot because it favors high humidity that enhances fungus colonization (Vail and Marois, 1991; Pezet et al., 2003; Mundy et al., 2012). Cluster compactness is highly determined by grape genetics and rootstock, therefore adding on the significance of cultivar selection in organic grape production (Table 2; Ferreira and Marais, 1987; Koblet et al., 1994; Cristinzio et al., 2000). In organic production, certain cultural practices such as manual cluster division and shoot topping at an appropriated time may contribute to reduce cluster compactness and further lower the occurrence of *Botrytis* infections on berries (Table 2; Molitor et al., 2012, 2015).

3. Crop protection in organic viticulture.

Maintaining a balanced ecosystem with minimal intervention may become challenging despite the implementation of an efficient pest and disease prevention program, especially when environmental conditions contribute to increase pest and disease pressure. When prevention methods become insufficient, different tools are available for organic growers to control pests and diseases.

3.1. *Organic pest management*

Despite correct implementation and maintenance of a natural biodiversity, variations in uncontrolled factors (i.e. climate) may contribute to break the equilibrium in the organic vineyard and press the grower to use specific measures to constrain plant enemies. Organic pest management primarily focuses on enhancing the presence of beneficial arthropods to the detriment of pests, using economical and low-impact practices that consider the ecosystem (Landis et al., 2005; Peverieri et al., 2009; Bruggisser et al., 2010). To reach this goal, taking advantage from biological and physical control, and from semiochemicals is an asset (Bostanian et al., 2012). Biological control recruits enemies of pests (e.g., predators, parasitoids, pathogens); physical control uses physical barrier against herbivores, whereas semiochemicals use signaling molecules to maintain pest away from crop (Bostanian et al., 2012).

3.1.1. *Biological control*

Biological control may be carried out using different approaches such as classical biological control, augmentation and conservation (Begon et al., 1996). Classical biological control involves introducing a natural enemy from a foreign geographical area, but its use is negligible in grape production because most attempts provided moderate successes (Flaherty and Wilson, 1999). In organic viticulture, biological control achieves better result to control pest with periodic releases of biological control agents (e.g. augmentation) and by using ecosystem managements (e.g. conservation) (Begon et al., 1996). Success factors in such approaches involve appropriate plant selection and diversity, maximization of ecosystem services, synchronicity between the natural enemy and the target pest, and considerations for the landscape scale and the dynamic of the agroecosystem (Landis et al., 2005; Zehnder et al., 2007; Fiedler et al., 2008). Several difficulties (e.g. lack of synchronization between prey and predator; intraguild predation) have been previously noted and resulted in little impact on the targeted pest, but successes have also been reported (Mani et al., 2014). For example, using conservation to increase the population of the egg parasitoid *Anagrus epos* (Girault) efficiently reduced the occurrence of the western grape leafhopper (*Erythroneura elegantula* Osborn) in organic California vineyards (Table 3; Altieri

Table 3
Examples of biological control against insects and mites in vineyards.

Pest species	Natural enemies	Biological control strategy	Topic of study	Impact on target pest	Refs.
Popillia japonica Newman	*Tiphia vernalis* Rohwer	classical	introduction and dispersion of the exotic parasitoid	reduced pest population	Britton and Johnson (1938)
Popillia japonica Newman	*Istocheta aldrichi* (Mesnil)	classical	introduction and impact of the exotic parasitoid	did not reduced pest population; lack of synchronization between pest and enemy	Fleming (1968)
Popillia japonica Newman	Nematodes, e.g. *Steinernema glaseri* (Steiner)	classical	large-scale evaluation of colonization by nematodes	colonization was unsuccessful	Gaugler et al. (1992)
Erythroneura elegantula (Osborn)	*Anagrus epos* (Girault)	conservation	prune tree in vineyard	egg parasitism increased only for the first generation with prune tree	Murphy et al. (1998) Corbett and Rosenheim (1996)
Erythroneura elegantula (Osborn) *Frankliniella occidentalis* (Pergande)	*Anagrus epos* Girault Generalists predators	conservation	vegetal corridor to increase the abundance of natural enemies	greater natural enemy populations near corridor; reduced abundance of thrips and leafhopper near corridor	Nicholls et al. (2000)
Erythroneura variabilis Beamer, *E. elegantula* Osborn	*Chrysoperla carnea*, (Stephens)	augmentation, inundative releases	inundative predator released at several densities	high predator releases densities efficiently reduced the population of leafhopper	Daane et al. (1996)
Erythroneura variabilis Beamer	spiders sp.	conservation	cover crops to enhance spider predation	cover crops increased spider populations but without significant impact on the pest	Hanna et al. (2003)
Paralobesia viteana (Clemens) *Desmia funeralis* (Hübner)	*Bacillus Thuringiensis* Berliner	augmentation, inundative releases	product efficiency	Bt efficiently controlled both Lepidoptera without negative impact on predator insects populations	Biever and Hosteiter (1975)
Lobesia botrana Denis & Schiffermueler	*Bacillus Thuringiensis* Berliner	augmentation, inundative releases	products efficiency in 11 cultivars	Bt efficiently controlled the pest but application methods should consider cultivar characteristics	Ifoulis and Savopoulou-Soultani (2004)
lepidoptera	natural enemies in vineyard and soil macro invertebrates	conservation	use of mulches to increase natural enemies	no impact on pests; mulches increased beetles, Hymenoptera, and spiders and decreased the population of predatory and parasitic Diptera and Hemiptera	Thomson and Hoffmann (2007)
leafhoppers	natural enemies	conservation	vegetal corridor to improve biodiversity of natural enemies	greater natural enemy populations near corridor; reduction of leafhoppers near corridor; increased egg parasitism of leafhopper by *Anagrus*	Nicholls et al. (2001)
Planococcus ficus Signoret	*Coccidoxenoides peregrinus* (Timberlake)	classical	introduction of the parasitoid to control mealybug	no significant difference in parasitism rates in presence of releases	Walton and Pringle (2002)
Planococcus ficus Signoret *Neopulvinaria innumerabilis* (Rathvon)	*Cryptolaemus montrouzeiri* Mulsant	classical	introduction of the coccinellid to control mealybug and cotton scale	after 50 years of releases, *C. montrouzeiri* reduced mealybugs and cotton scale populations, but their control was variable according to region climate	Yasnosh et al. (2001)
Endopiza viteana (Clemens)	*Trichogramma minutum* Riley	augmentation, inundative releases	releases of *T. minutum* in border rows of vineyard	reduction of economic injury caused by grape berry moth	Nagarkatti et al. (2003)
Phytophagous mites, Tetranychidae and Eriophyids	predatory mites, Phytoseiidae	augmentation	releases of Phyoseiidae to control mites and their interaction with native phytoseiids	intraguild interactions between predators were observed and phytophagous mites populations were reduced	Duso and Vettorazzo (1999)
Panonychus ulmi (Koch)	predatory mites, Phytoseiidae	augmentation, inoculative releases	releases of Phyoseiidae to control mites and their interaction with native phytoseiids	intraguild predation reduced efficiency of mite control but in presence of predators compatibility, *P. ulmi* populations were reduced	Camporese and Duso (1996)
Panonychus ulmi (Koch)	*Typhlodromus pyri* Scheuten	augmentation	release of *T. pyri* in vineyard to control *P. ulmi*	*T. pyri* efficiently controlled *P. ulmi*, even in presence of *Amblyseius fallacis* (Garman)	Marshall and Lester (2001)

et al., 2005; Nicholls et al., 2000, 2001). Augmentation and inundative releases of *Bacillus thuringiensis* successfully controlled the grape berry moth (*Paralobesia viteana* Clemens) and the European grapevine moth (*Lobesia botrana* Den. & Schiff.) without negative impact on predator insects populations (Biever and Hosteiter, 1975; Ifoulis and Savopoulou-Soultani, 2004).

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3.1.2. Physical control practices

Physical control practices consist in the exclusion of insect pest by the use of physical barriers such as nets (Mannini, 2007) and kaolin clay (Valizadeh et al., 2013). Physical control in perennial crop is often labor consuming, restrictive, and costly (Vincent et al., 2003). In organic viticulture, physical control methods alone can only help for a number of insect pests including the leafhopper *Homalodisca vitripennis* (Say) (Blua et al., 2005; Tubajika et al., 2007), the vine cicada *Psalmocharias alhageos* (Kolonati) (Valizadeh et al., 2013) and the Rose chafer *Macrodactylus subspinosus* (F.) (Dubé et al., 2016). However, they may successfully complement other practices, such as biological or cultural control. For example, combining net protection and hot water treatments efficiently prevents the propagation of phytoplasma diseases, which are mostly propagated by insect vectors (Mannini, 2007). Certain physical barriers (e.g. screen barrier) may be repulsive on pests and limit insect vector dispersion. For instance, physical barrier efficiently limited the dispersion of leafhoppers and consequently reduced the propagation of both Pierce's disease and phytoplasma diseases (Blua et al., 2005; Mannini, 2007). Indeed, repellents such as kaolin clay are effective to control various insects like leafhoppers and beetles in organic viticulture and may, in some cases, effectively replace insecticide treatments by causing a repulsive effect that consequently reduces pest occurrence (Tubajika et al., 2007; Valizadeh et al., 2013; Bostanian et al., 2012).

3.1.3. Semiochemical

Semiochemicals like pheromones and kairomones are molecules that serve communication purposes between individuals from a same or a different species (Bostanian et al., 2012). They can efficiently attract insects even at low population densities, they are species-specific, they have little adverse impacts on natural enemies and their persistence in the field is generally longer than insecticides (Witzgall et al., 2010). In organic vineyard, sex pheromones are mostly used to monitor the presence and abundance of a specific pest (pest detection), as massive trapping agent, and for mating disruption (Table 4; Witzgall et al., 2010). Trapping provides essential data to optimize application of control measures and particular consideration must be done for the nature of the attractant, the dispenser, the design and location of the trap, and the lure quality (Witzgall et al., 2010). In vineyard, mass trapping is particularly efficient against the Japanese beetle (*Popillia japonica* Newman), the redbanded leafroller (*Argyrotaenia velutinana* Walker) and the grape berry moth (Table 4) (Taschenberg et al., 1974; Wold-Burkess, 2011).

Sex pheromones can also prevent mating by disrupting insect communication, which constitute the most common use of semiochemicals in organic control of pest populations. Some studies have demonstrated successful control using sex pheromones mainly for *L botrana*, *Eupoecilia ambiguella* (Hübner) and *Planococcus ficus* (Signoret) (Table 4; Kast, 2001; Millar et al., 2002; Moschos et al., 2004; Carlos et al., 2005). Success of mating disruption depends on several factors including optimal understanding of the mechanisms underlying mating disruption, appropriate pheromone blends, rate of release, aerial concentration and scale of application (Varner et al., 2001; Witzgall et al., 2010).

3.1.4. Chemical control with natural products

In organic crop production, chemical control is only used when all other methods have failed. Only a few non-synthetic chemicals are accepted in organic grape production. Most organic chemical insecticides originate from plant extracts or mineral sources. Approval of non-synthetic chemicals for organic production is legislated by country regulations that can restrict the use of a particular product. For example, insecticides such as spinosad and azadirachtin are both authorized in some countries and not in others. Indeed, spinosad is known to be highly toxic to pollinators and beneficial insects (Gentz et al., 2010). Azadirachtin is a substance extracted from the neem tree (*Azadirachta indica*) seed oil and has minimal impacts on beneficial arthropods (Mani et al., 2014; Mazzoni et al., 2003). Its insect-killing property is especially efficient at immature stage; therefore, with the exception of coccinellids, it generally allows the preservation of adult predators (Mani et al., 2014). Azadirachtin prove to be a promising product against *Scaphoideus titanus* Ball and *M. subspinosus* in vineyards under organic or integrated pest management, especially in preventive strategies and short-term activity, as the efficiency of Azadirachtin residues decreases significantly after three days in the field (Mazzoni et al., 2003; Isaacs et al., 2004).

Other products frequently used to reduce pest population in organic vineyard either contain sulfur, pyrethrin, oils (e.g. summer oil, dormant oil), or insecticidal soap (Bostanian et al., 2012; Mani et al., 2014; Rombourgh, 2002). Oils and insecticidal soap are known to efficiently control mites such as *Tetranychus urticae* Koch, *Panonychus ulmi* (Koch) and *Colomerus vitis* (Pagenstecher) in vineyards (Bostanian et al., 2012). According to Rousseau (1997), sulfur and paraffin oil applications after bud break might help reduce the population of *S. titanus* and consequently the occurrence of Flavescence dorée in organic vineyard,

3.2. Treating fungal diseases in organic grape production

Copper is largely used in organic grape production because of its unique properties as a wide-spectrum fungicide and bactericide, and its high efficiency against downy mildew (Dagostin et al., 2011). The use of copper in grape production began in the late 1800s, when the Bordeaux mixture, a broad-spectrum fungicide composed of copper sulfate and slaked lime, was discovered (Martins et al., 2014). It has been used extensively in viticulture for more than 150 years, at rates reaching 80 kg/ha/year (Dagostin et al., 2011). But copper has a low mobility in soil causing it to accumulate to levels that may be toxic (Komárek et al., 2010). Therefore, its use must be carefully dosed (Komárek et al., 2010). Recently, over a hundred different treatments including biocontrol agents, materials of animal origin, homeopathic preparations, inorganic materials, microbial extracts, natural derivatives, plant extracts, physical methods, and synthetic materials, were screened against downy mildew but none of these treatments were as efficient as copper against this disease (Dagostin et al., 2011).

In Europe, the use of copper is limited to 6 kg/ha/yr in organic viticulture (Mackie et al., 2013). Copper is a contact fungicide that loses its efficiency with plant tissue expansion and particle displacement by rain, so frequent sprayings may be required to keep fungal diseases under control in organic farming (Kuflik et al., 2009). When meteorological conditions maintain high disease pressure on the organic vineyard, one application per week may be necessary (Kuflik et al., 2009).

Fungicides based on other mineral elements like sulfur and lime are approved in organic production and frequently used in combination with or without copper. In practice, they are known to efficiently reduce major diseases and to be harmless for the fauna (Rombourgh, 2002). Direct contact with the fungus is generally necessary to efficiently control its development (Rombourgh, 2002). Sulfur is one of the most widely used mineral-based fungicides in grape production because of its high efficacy and its broad applicability against fungal diseases (Griffith et al., 2015). It is therefore largely used in organic farming (Griffith et al., 2015). In viticulture, sulfur can only be used until veraison to avoid the formation of hydrogen sulfide during fermentation, which causes unwanted off-flavors in wine (Griffith et al., 2015). Mineral-based formulations including copper or sulfur can be used alternately with other

Table 4
Overview of the use of semiochemicals and pheromones for detection (D), population monitoring (PM), mass trapping (MT), and mating disruption (MD) in vineyard from different countries.

Pest species	Purpose	Country	Refs.
Archips argyrospila (Walker); *Argyrotaenia velutinan* (Walter); *Platynota* sp.	D	Canada	Hillier and Lefebvre (2012)
Argyrotaenia velutinana (Walker); *Paralobesia viteana* (Clemens)	MT, MD	United States	Taschenberg et al. (1974)
Cryptoblabes gnidiella Mill.; *Lobesia botrana* Den. & Schiff	MD	Israel	Harari et al. (2007) Gordon et al. (2003)
Endopiza viteana Clemens	MD	Canada	Trimble et al. (2003)
	PM	United States	Danko and Jubb (1983)
Eupoecilia ambiguella (Hübner); *Lobesia botrana* Den. & Schiff	MD	Germany	Kast (2001)
	MD	France	Roehrich et al. (1979)
Eupoecilia ambiguella (Hübner); *Lobesia botrana* Den. and Schiff; *Sparganothis pilleriana* (Schiff.)	MD	Switzerland	Arn et al. (1988)
Lobesia botrana Den. & Schiff	MD	Portugal	Carlos et al. (2005)
	MD	Greece	Moschos et al. (2004)
	MD	Switzerland	Charmillot and Pasquier (2001)
	MD	Italy	Varner et al. (2001)
Popillia japonica Newman	MT	United States	Wold-Burkess (2011)
Planococcus ficus (Signoret)	PM	United States	Millar et al. (2002)
	PM	South Africa	Walton et al. (2004)
	MD	Italy	Cocco et al., (2011)
	MD	United States	Walton et al. (2006)
	PM	Italy	Lentini et al. (2008)
Pseudococcus sp.	D, PM	United States	Dreves and Walton (2010)
Pseudococcus maritimus (Ehrhorn)	PM	United States	Bahder et al. (2013)
	PM	United States	Walton et al. (2013)
Sparganothis pilleriana (Schiff.)	MD	Germany	Schmidt-Tiedemann et al. (1999)

products such as garlic extract, potassium bicarbonate, citric acid, and hydrogen peroxide (Rombourgh, 2002).

The development of nontoxic materials to control diseases has resulted in various approaches: some act as physical barrier, others are biological agents, and some are poisonous to the disease. In addition to its insect repellent properties, Kaolin can also reduce diseases incidence (Sholberg and Boulé, 2006). Similarly, several products used in organic management contain biological agents such as *Streptomyces griseoviridis* (soil bacteria; e.g. Mycostop) (Tapio and Pohto-Lahdenperä, 1991), *Bacillus subtilis* (e.g. Serenade) (Ferreira et al., 1991), *Ampelomyces quisqualis* (e.g. AQ-10) (Kiss et al., 2004) and *Trichoderma harzianum* (e.g. Supresivit, Trichodex) (Elad, 1994) that reduce diseases occurrence and severity (Jacometti et al., 2010; Rombourgh, 2002).

4. Impact of organic management on wine quality

According to recent data (Barber et al., 2009; Rojas-Méndez et al., 2015), organic wines are thought to be healthier and to contain lower amounts of pesticide than conventional wine. Studies show that most pesticides are removed by the winemaking process, leaving insignificant amounts of residue in conventional wine (Cabras and Angioni, 2000; Bonn et al., 2015). Yet other studies found that certain fungicide may remain in wine even after six-month of storage (Debieu et al., 2001), or carry-over from recycled wooden barrels and lies (*pied de cuve*) to new wine (Plana, 2013).

Besides being free of synthetic pesticides, many organic wines contain lower amounts of sulfur dioxide than conventional wines (Guerrero and Cantos-Villar, 2015), which may constitute a commercial advantage (Costanigro et al., 2014). For example, in the USA, "organic wine" only contains naturally occurring sulfur dioxide and "wines made from organic grapes" may contain up to 100 mg/L of total sulfur dioxide (USDA, 2015b), whereas the European Commission allows sulfur dioxide addition up to 100 mg/L in red and 150 mg/L in white and rose wines (Guerrero and Cantos-Villar, 2015). In contrast with conventional winemaking, the yeast nutrient diammonium phosphate (DAP) is prohibited in USA for organic winemaking, as are copper citrate and copper sulfate that are typically used to treat aromatic defaults (USDA, 2015b). The National Organic Program of the USDA (2015b) allows the use of enzymes if they derive from edible, nontoxic and nonpathogenic plant or fungal material, whereas the EU Commission prohibits the use of β-glucanase, urease and lyzosymes (European Commission, 2013).

Otherwise, organic winemaking regulations say little about other potential contaminants such as plasticizers (e.g., phthalates). Plasticizers are known to migrate into wine from the equipment and supplies, including piping, tanks, stoppers and plastic containers (Jung et al., 2009; Jurica et al., 2013; Russo et al., 2012). In adult men, exposure to phthalates has been related to a number of health issues such as DNA damages in spermatozoids, decrease in sperm motility and increased waist circumference (Meeker et al., 2009). Because these substances are not controlled in organic winemaking, their level in organic and conventional wines may be similar although, to our knowledge, no studies investigated this topic so far.

The potential impact of organic grape management on wine properties is unclear: Does organic viticulture increase wine healthiness? Does it improve wine sensory attributes? Does mineral pesticides such as copper carry over to wine? Studies comparing the quality of organic to conventional wine face many challenges related to the respective requirements of both production systems. For example, to fairly compare both systems, organic and conventional plots should share similar environment and practices, excluding the inputs and practices prohibited in organic production, which can be hardly achievable at the commercial level. Such trials should also be carried out on similar grape varieties as varietal differences are often larger than those observed between growing or winemaking conditions (Brandt and lgaard, 2001). In these conditions, keeping the number of uncontrolled variables within an acceptable range is often difficult. So far, studies comparing organic and conventional growing systems mostly addressed the carry-over of mineral pesticides such as copper from grape to grape juice or wine (Provenzano et al., 2010; Miele et al., 2015), and the impact of organic management on grape and wine composition (Cozzolino et al., 2009; Mulero et al., 2009), wine's sensory attributes (Martin and Rasmussen, 2011), wine's healthiness (Yildirim et al., 2007; Mulero et al., 2010; Bunea et al., 2012; Tassoni et al., 2013; Granato et al., 2014), and fermentation microbiota (Cordero-Bueso et al., 2011).

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4.1. Carry-over of mineral-based pesticides

Copper is a toxic molecule for both plants and animal when absorbed in high levels. So far, studies showed that most copper precipitates during the winemaking process (Miele et al., 2015). The typical copper concentration in conventional wine ranges between 0.02 and 3 mg/L but should remain below 0.5 mg/L to avoid spoilage reactions (e.g., pinking, browning, haze) (da Costa et al., 2014). In addition, its presence may significantly affect the fermentation kinetics of *S. cerevisieae* yeasts in a strain-dependent manner (Ferreira et al., 2006). Copper may also impact the level of aromatic thiols in Sauvignon blanc grapes and wines, but the impact is reduced when copper is only sprayed on foliage (Darriet et al., 2001).

Despite the significant use of copper in organic viticulture, its level in organic grapes and wines have been found to remain below the maximum levels of 20 mg/kg (berries) and 1 mg/L (wine) in Italy (Provenzano et al., 2010). Conversely, copper concentration in organic grape juice commercially produced from *V. labrusca* varieties in Brazil ranged from 0.23 to 12.4 mg/L, which is twice the maximum limit of 5 mg/L allowed for organic food in that country, and four times higher than the maximal copper concentration generally found in conventional wines (da Costa et al., 2014; Miele et al., 2015).

4.2. Grape-related compounds: wine composition, sensory perception and healthiness

The general assumption is that organic grapevines suffer more biotic stresses than conventional vines and should therefore produce higher rates of secondary metabolites, including phenolic compounds (Martin and Rasmussen, 2011). According to a study by Mulero et al. (2009), wines produced from organic and conventional grapes harvested in the same location and fermented using a similar protocol only showed negligible difference in their respective phenolic profiles (n = 18). At the beginning, organic wines showed significantly higher levels of anthocyanin (344 mg/L) and *trans*-resveratrol-3-*o*-glucoside (14 mg/L) than conventional wines (296 mg/L and 12 mg/L, respectively), but after six month of shelf-life, these differences where not detectable anymore; at this time, organic wines rather showed significantly higher level of hydroxycinnamic derivatives (48 mg/L) compared to conventional wines (41 mg/L) (Mulero et al., 2009). Recently, Cozzolino et al. (2009) compared the mid-infrared spectra of both commercial organic wines (n = 57) and non-organic wines (n = 115) and were able to discriminate between them based on the phenolic compound structures whose band resonate at 1268 cm^{-1}, hence supporting the assumption that organic and conventional wines do result in different phenolic profiles (Cozzolino et al., 2009).

In an effort to reduce experimental variability, Martin and Rasmussen (2011) used geographically paired monovarietal wines produced in five California wine countries, using the same winemaking protocol. In these wines, the concentration of total phenolic (TP) compounds was significantly higher in organic Pinot noir wines (3500–5860 mg/L gallic ac. eq.) compared to conventional ones (2630–4630 mg/L gallic ac. eq.), whereas conventional Syrah wines showed higher levels of TP (5240–8380 mg/L gallic ac. eq.) compared to organic ones (3700–4550 mg/L gallic ac. eq.), suggesting that grape varieties may react differently to organic production methods. However, wine sensory analysis showed no noticeable difference in the visual aspect, the aroma intensity and quality, nor the taste of organic and conventional wines (Martin and Rasmussen, 2011).

Higher rates of phenolic compounds or other health-related compounds in organic wine comply with consumer perception that they are healthier. However, studies presented above (Cozzolino et al., 2009; Mulero et al., 2009; Martin and Rasmussen, 2011) suggest that such trends remain to be fully demonstrated. In addition, organic wines may carry higher rates of unwanted biogenic amines. For instance, wines made from organic grapes showed higher levels of putrescine (5.55 mg/L) than wines issued from conventional grapes (3.68 mg/L) despite both being similarly processed (e.g. using sulfur dioxide to prevent microbial contamination) (Yildirim et al., 2007). Biogenic amines in food may cause headaches, heart palpitation and allergenic disorders (Yildirim et al., 2007; Comuzzo et al., 2013). Many studies compared the health properties of organic juice and wine to those of conventional products by measuring their *in vitro* antioxidant activity (Mulero et al., 2010; Bunea et al., 2012; Tassoni et al., 2013; Granato et al., 2014) and their *in vivo* impact on neuroprotection (Rodrigues et al., 2012), on low-density lipoprotein oxidation (Yildirim et al., 2004), on hepatoprotection, and antioxidant potential (Buchner et al., 2014). These studies showed little or no significant differences between organic and conventional products.

4.3. Grape-related microorganism: fermentation microbiota

Many pesticides have a microbiocidal activity, therefore grapes grown under organic management show higher occurrence and diversity of wild yeast and bacteria that may contribute to wine fermentation, including non-*Saccharomyces* species such as *Candida*, *Hanseniaspora*, *Hansenula*, *Issatchenkia*, *Kluyveromyces*, *Metschnikowia*, *Pichia*, *Torulaspora* and *Zygosaccharomyces* (Cordero-Bueso et al., 2011). Cordero-Bueso et al. (2011) showed significant differences in the respective yeast populations found on organic Shiraz, Grenache, and Barbera grapes when compared to those of conventional grapes. For example, five yeast species (e.g., *Saccharomyces cerevisiae* (17.1% of total yeast population), *Candida stellata* (15.2%), *Hanseniaspora guilliermondii* (28.6%), *Kluyveromyces thermotolerans* (20%) and *Pichia anomala* (19.1%)) were found on organic Grenache grapes, whereas conventional Grenache berries only carried two species: *Hanseniaspora guilliermondii* (33.3%), *Kluyveromyces thermotolerans* (66.7%). There is growing evidence that non-*Saccharomyces* yeasts constitute a significant part of wine microbial population during fermentation and contribute to desirable sensory attributes to wine (Esteve-Zarzoso et al., 1998; Jolly and Augustyn, 2006).

Despite the complexity of spontaneous fermentations and the risks associated with wine and equipment contamination, yeast biodiversity could be a competitive advantage in organic grape production. Autochthonous yeasts and other environment-related microorganisms might play a role in the development of unique *terroir*-related characteristics in wine and could thus contribute to build a signature identity for organic wines from specific areas. But evidence that organic grape and wine production is beneficial to wine flavors and taste remains to be demonstrated. In fact, organic grapes show higher rates of polyphenol oxidases (PPO) activity compared to conventional grapes, suggesting that their processing may be more challenging than that of conventional grapes, especially under regulations prohibiting sulfur dioxide (Núñez-Delicado et al., 2005). Sulfur reduction or avoidance involves higher risks of oxidation and microbial contamination, either during the winemaking process itself, or during shelf life. A number of inputs such as bacteriocins, wine phenolics, chitosan and lysozyme, and several physical methods including UV treatments, pulsed electric fields and high hydrostatic pressure have been tested in order to replace sulfur dioxide in wine (see the review of Guerrero and Cantos-Villar, 2015). However, besides the fact that none of these practices provided a real replacement for sulfur dioxide (Guerrero and Cantos-Villar, 2015), most of them entailed the use of chemicals and/or processes that are not allowed in organic wine production, or that could be misleading with regards to consumers expectations of organic wine nature.

In order to reduce the production of oxidative off-flavors during nonsulfited organic winemaking, Balboa-Lagunero et al. (2013) proposed to carry fermentation using yeasts strains showing high consumption rates of amino acids known to act as precursors for oxidation attributes in wine (e.g. phenylalanine, methionine, leucine). Certain strains successfully reduced the occurrence of oxidation-related aldehydes as well as the intensity of off-flavors in wine made without sulfites (Balboa-Lagunero et al., 2013).

5. Conclusion

Success in organic grape and wine production requires consideration of the vineyard as a balanced ecosystem where the surrounding flora and fauna contribute to maintain the balance towards grapevine growth and productivity, while maintaining pests, diseases, and weeds at the lowest level. Implementing cultural practices and conditions that optimize canopy microclimate and populations of beneficial insects and microorganisms is essential for this purpose. However, the use of pesticides such as copper-based fungicide may still be needed when disease pressure increases, making the accumulation of copper in soils a challenging limitation for organic wine production, especially in area with high disease pressure.

Despite the constraints encountered at all stages, organic wine production represents an opportunity for grape growers and winemakers to develop wines unique to their *terroir* that are distinct from conventional wines, and position themselves into this niche as the demands for sustainable food products will continue to grow. Therefore, studies aiming at improving organic grape production and organic wine quality at every step will be of crucial value in the near future for this industry. Solutions may include improving organic management through the use of fungus-resistant grape varieties and find alternatives for sulfur dioxide and other restricted products in organic winemaking.

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Appendix A. Supplementary data

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References

Adams, K.E., 2011. Influence of Vineyard Floor Management Practices on Soil Aggregate Stability, Total Soil Carbon and Grapevine Yield Master Degree Thesis. California Polytechnic State University/San Luis Obisco, CA, USA, pp. 72 (accessed 29.07.15). http://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1649&context=theses.

Altieri, M.A., Ponti, L., Nicholls, C.I., 2005. Manipulating vineyard biodiversity for improved insect pest management: case studies from northern California. Int. J. Biodivers. Sci. Manag. 1, 191–203.

Arn, H., Rauscher, S., Guerin, P., Buser, H.R., 1988. Sex pheromone blends of three tortricid pests in European vineyards. Agric. Ecosyst. Environ. 21, 111–117.

Aubertot, J.N., Barbier, J.M., Carpentier, A., Gril, J.J., Guichard, L., Lucas, P., Savary, S., Voltz, M., Savini, I., 2005. Pesticides, agriculture et environnement: Réduire l'utilisation des pesticides et en limiter les impacts environnementaux. In:Sabbagh, C., de Menthière, N. (Eds), INRA/Cemagref Report, 68 p. (accessed 5.07.15, http://www.observatoire-pesticides.fr/upload/bibliotheque/704624261252893935317453066156/pesticides_synthese_inra_cemagref.pdf).

Austin, C.N., Wilcox, W.F., 2011. Effects of fruit-zone leaf removal training systems, and irrigation on the development of grapevine powdery mildew. Am. J. Enol. Vitic. 62, 193–198.

Austin, C.N., Grove, G.G., Meyers, J.M., Wilcox, W.F., 2011. Powdery mildew severity as a function of canopy density: associated impacts on sunlight penetration and spray coverage. Am. J. Enol. Vitic. 62, 23–31.

Austin, C., 2010. Sunlight's Influence on Grapevine Powdery Mildew: Direct Effects on Pathogen Development and Attendant Consequences of Canopy Management and Vineyard Variability. Doctoral Thesis. Cornell University, New York, USA.

Avenard, J.C., Bernos, L., Grand, O., Samir, B., 2003. Manuel de Production Intégrée en Viticulture. Éditions Féret, Bordeaux, pp. 222.

Bahder, B.W., Naidu, R.A., Daane, K.M., Millar, J.G., Walsh, D.B., 2013. Pheromone-based monitoring of *Pseudococcus maritimus* (Hemiptera: Pseudococcidae) populations in Concord grape vineyards. J. Econ. Entomol. 106, 482–490.

Balboa-Lagunero, T., Arroyo, T., Cabellos, J.M., Aznar, M., 2013. Yeast selection as a tool for reducing key oxidation notes in organic wines. Food Res. Int. 53, 252–259.

Barber, N., Taylor, C., Strick, S., 2009. Wine consumers' environmental knowledge and attitudes: influence on willingness to purchase. Int. J. Wine Res. 1, 59–72.

Bayramoglu, Z., Gundogmus, E., 2008. Cost efficiency on organic farming: a comparison between organic and conventional raisin-producing households in Turkey. Span. J. Agric. Res. 1, 3–11.

Begon, M., Harper, J.L., Townsed, C.R., 1996. Ecology, third edition. Blackwell Science, London, pp. 752.

Begum, M., Gurr, G.M., Wratten, S.D., Hedberg, P.R., Nicol, H.I., 2006. Using selective food plants to maximize biological control of vineyard pests. J. Appl. Ecol. 43, 547–554.

Bergqvist, J., Dokoozlian, N., Ebisuda, N., 2001. Sunlight exposure and temperature effects on berry growth and composition of Cabernet Sauvignon and Grenache in the Central San Joaquin Valley of California. Am. J. Enol. Vitic. 52, 1–7.

Bern, B.P., Bogo, A., Everhart, S., Casa, R.T., Gonçalves, M.J., Marcon Filho, J.L., da Cunha, I.C., 2015. Effect of Y-trellis and vertical shoot positioning training systems on downy mildew and botrytis bunch rot of grape in highlands of southern Brazil. Sci. Hortic. 185, 162–166.

Berndt, L.A., Wratten, S.D., Scarratt, S.L., 2006. The influence of floral resource subsidies on parasitism rates of leafrollers (Lepidoptera: Tortricidae) in New Zealand vineyards. Biol. Control 37, 50–55.

Biever, K.D., Hosteiter, D.L., 1975. *Bacillus thuringiensis* against lepidopterous pests of wine grapes in Missouri. J. Econ. Entomol. 68, 66–68.

Blua, M.J., Campbell, K., Morgan, D.J.W., Redak, R.A., 2005. Impact of a screen barrier on dispersion behavior of *Homalodisca coagulata* (Hemiptera: Cicadellidae). J. Econ. Entomol. 98, 1664–1668.

Bonn, M.A., Cronin, J.J., Cho, M., 2015. Do Environmental Sustainable Practices of Organic Wine Suppliers Affect Consumers' Behavioral Intentions? The Moderating Role of Trust. Cornell Hospitality Quarterly (1938965515576567).

Bordelon, B.P., Weller, S.C., 1997. Preplant cover crops affect weed and vine growth in first-year vineyards. HortScience 32, 1040–1043.

Bostanian, N.J., Vincent, V., Isaacs, R., 2012. Arthropod Management in Vineyards: Pests, Approaches, and Future Directions. Springer, pp. 505.

Brandt, K., Igaard, J.P., 2001. Organic agriculture: does it enhance or reduce the nutritional value of plant foods? J. Sci. Food Agric. 81, 924–931.

Britton, W.E., Johnson, J.P., 1938. The Japanese beetle in Connecticut. Conn. Agric. Exp. Stn. Bull. 411, 455–486.

Bruggisser, O.T., Schmidt-Entling, M.H., Bacher, S., 2010. Effects of vineyard management on biodiversity at three trophic levels. Biol. Conserv. 143, 1521–1528.

Buchner, I., Medeiros, N., Lacerda, D., Normann, C., Gemelli, T., Rigon, P., Wannmacher, C., Henriques, J., Dani, C., Funchal, C., 2014. Hepatoprotective and antioxidant potential of organic and conventional grape juices in rats fed a high-fat diet. Antioxidants 3, 323–338.

Bunea, C.I., Pop, N., Babes, A.C., Matea, C., Dulf, F.V., Bunea, A., 2012. Carotenoids, total polyphenols and antioxidant activity of grapes (Vitis vinifera) cultivated in organic and conventional systems. Chem. Cent. J. 6 (1–1).

Cabras, P., Angioni, A., 2000. Pesticide residues in grapes, wine, and their processing products. J. Agric. Food Chem. 48, 967–973.

Cabras, P., Conte, E., 2001. Pesticide residues in grapes and wine in Italy. Food Addit. Contam. 18, 880–885.

Camporese, P., Duso, C., 1996. Different colonization patterns of phytophagous and predatory mites (Acari: Tetranychidae, Phytoseiidae) on three grape varieties: a case study. Exp. Appl. Acarol. 20, 1–22.

Carlos, C., Costa, J., Gaspar, C., Domingos, J., Alves, F., Torres, L., 2005. Mating disruption to control grapevine moth, *Lobesia botrana* (Den. and Schiff.) in Porto wine region: a three-year study. IOBC WPRS Bull. 28, 283.

Charmillot, P.J., Pasquier, D., 2001. Technique de confusion, lutte classique et dynamique des populations des vers de la grappe. IOBC wprs Bull. 24, 87–90.

Chellemi, D.O., Marois, J.J., 1992. Influence of leaf removal fungicide applications, and fruit maturity on incidence and severity of grape powdery mildew. Am. J. Enol. Vitic. 43, 53–57.

Cilindre, C., Castro, A.J., Clément, C.P., Jeandet, P., Marchal, R., 2007. Influence of *Botrytis cinerea* infection on Champagne wine proteins (characterized by two-dimensional electrophoresis/immunodetection) and wine foaming properties. Food Chem. 103, 139–149.

Cocco, A., Coinu, M., Lentini, A., Serra, G., Delrio, G., 2011. Mating disruption field trials to control the vine mealybug *Planococcus ficus*. IOBC/WPRS Bull. 67, 215–221.
Coleman, D.C., Odum, E.P., Crossley Jr., D.A., 1992. Soil biology, soil ecology, and global change. Biol. Fertil. Soils 14, 104–111.
Coll, P., Le Cadre, E., Blanchart, E., Hinsinger, P., Villenave, C., 2011. Organic viticulture and soil quality: a long-term study in Southern France. Appl. Soil Ecol. 50, 37–44.
Commentil, P., Brunet, L., Audran, J.C., 1997. The development of the grape berry cuticle in relation to susceptibility to bunch rot disease. J. Exp. Bot. 48, 1599–1607.
Comuzzo, P., Rauhut, D., Werner, M., Lagazio, C., Zironi, R., 2013. A survey on wines from organic viticulture from different European countries. Food Control 34, 274–282.
Corbett, A., Rosenheim, J.A., 1996. Impact of a natural enemy overwintering refuge and its interaction with the surrounding landscape. Ecol. Entomol. 21 (2), 155–164.
Cordero-Bueso, G., Arroyo, T., Serrano, A., Tello, J., Aporta, I., Vélez, M.D., Valero, E., 2011. Influence of the farming system and vine variety on yeast communities associated with grape berries. Int. J. Food Microbiol. 145, 132–139.
Costanigro, M., Appleby, C., Menke, S.D., 2014. The wine headache: consumer perceptions of sulfites and willingness to pay for non-sulfited wines. Food Qual. Preference 31, 81–89.
Costello, M.J., Daane, K.M., 2003. Spider and leafhopper (*Erythroneura* spp.) response to vineyard ground cover. Environ. Entomol. 32, 1085–1098.
Cozzolino, D., Holdstock, M., Dambergs, R.G., Cynkar, W.U., Smith, P.A., 2009. Mid infrared spectroscopy and multivariate analysis: a tool to discriminate between organic and non-organic wines grown in Australia. Food Chem. 116, 761–765.
Cristinzio, G., Iannini, C., Scaglione, G., Boselli, M., 2000. Effect of rootstocks on *Botrytis cinerea* susceptibility of *Vitis vinifera* cv. Falanghina. Adv. Hortic. Sci. 2, 83–86.
Daane, K.M., Williams, L.E., 2003. Manipulating vineyard irrigation amounts to reduce insect pest damage. Ecol. Appl. 13, 1650–1666.
Daane, K.M., Yokota, G.Y., Zheng, Y., Hagen, K.S., 1996. Inundative release of common Green Lacewings (Neuroptera: Chrysopidae) to suppress *Erythroneura variabilis* and *E. elegantula* (Homoptera: Cicadellidae) in Vineyards. Environ. Entomol. 25, 1224–1234.
Dagostin, S., Schärer, H.-J., Pertot, I., 2011. Are there alternatives to copper for controlling grapevine downy mildew in organic viticulture? Crop Prot. 30, 776–788.
Danko, L., Jubb, G.L., 1983. Field evaluation of pheromone-baited traps for monitoring grape berry moth (Lepidoptera: Olethreutidae). J. Econ. Entomol. 76, 480–483.
Darriet, P., Bouchilloux, P., Poupot, C., Bugaret, Y., Clerjeau, M., Sauris, P., Medina, B., Dubourdieu, D., 2001. Effects of copper fungicide spraying on volatile thiols of the varietal aroma of Sauvignon blanc, Cabernet Sauvignon and Merlot wines. Vitis 40, 93–99.
Debieu, D., Bach, J., Hugon, M., Malosse, C., Leroux, P., 2001. The hydroxyanilide fenhexamid: a new sterol biosynthesis inhibitor fungicide efficient against the plant pathogenic fungus Botryotinia fuckeliana (*Botrytis cinerea*). Pest Manag. Sci. 57, 1060–1067.
Delière, L., Cartolaro, P., Léger, B., Naud, O., 2014. Field evaluation of an expertise-based formal decision system for fungicide management of grapevine downy and powdery mildews. Pest Manag. Sci. 71, 1247–1257.
Draganov, D., Draganov, G., 1976. Influence of planting density, training, and vine microclimate on the quantity and quality of wine grapes. Gradinarska Lozar. Nauka 13, 97–109.
Dreves, A.J., Walton, V.M., 2010. Trapping and identifying mealybugs in Oregon vineyards. Corvallis, OR: Extension Service, Oregon State University. http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/13751/em8998.pdf (accessed 29.07.15).
Dubé, G., Bélair, G., Côté, M., Harnois, M., Roy, M., 2012. Répression du scarabée du rosier en viticulture biologique., Final report 08-BIO-39. 34 p.
Duncan, R.A., Stapleton, J.J., Leavitt, G.M., 1995. Population dynamics of epiphytic mycoflora and occurrence of bunch rots of wine grapes as influenced by leaf removal. Plant Pathol. 44, 956–965.
Duso, C., Vettorazzo, E., 1999. Mite population dynamics on different grape varieties with or without phytoseiids released (Acari: Phytoseiidae). Exp. Appl. Acarol. 23, 741–763.
Elad, Y., 1994. Biological control of grape grey mould by *Trichoderma harzianum*. Crop Prot. 13, 35–38.
Elmer, P.A., Michailides, T.J., 2007. Epidemiology of *Botrytis cinere*a in orchard and vine crops. In: Botrytis: Biology Pathology and Control. Springer, Dordrecht, Netherlands, pp. 243–272.
English, J.T., Thomas, C.S., Marois, J.J., Gubler, W.D., 1989. Microclimates of grapevine canopies associated with leaf removal and control of Botrytis bunch rot. Phytopathology 79, 395–401.
Esteve-Zarzoso, B., Manzanares, P., Ramón, D., Querol, A., 1998. The role of non-Saccharomyces yeasts in industrial winemaking. Int. Microbiol. 1, 143–148.
European Commission, 2013. Facts and figures on organic agriculture in the European Union. Agric. Rural Dev. Eur. Comm., 46.
Ferree, D.C., Ellis, M.A., McArtney, S.J., Brown, M.V., Scurlock, D.M., 2003. Comparison of fungicide, leaf removal and gibberellic acid on development of grape clusters and botrytis bunch rot of 'Vignoles' and 'Pinot Gris'. Small Fruits Rev. 2, 3–18.
Ferreira, J.H.S., Marais, P.G., 1987. Effect of rootstock cultivar: pruning method and crop load on Botrytis cinerea rot of Vitis vinifera cv. Chenin blanc grapes. S. Afr. J. Enol. Vitic. 8, 41–44.
Ferreira, J.H.S., Matthee, F.N., Thomas, A.C., 1991. Biological control of *Eutypa lata* on grapevine by an antagonistic strain of Bacillus subtilis. Phytopathology 81, 283–287.
Ferreira, J., Toit, M.D., Toit, W.J.D., 2006. The effects of copper and high sugar concentrations on growth, fermentation efficiency and volatile acidity production of different commercial wine yeast strains. Aust. J. Grape Wine Res. 12, 50–56.
Fiedler, A.K., Landis, D.A., Wratten, S.D., 2008. Maximizing ecosystem services from conservation biological control: the role of habitat management. Biol. Control 45, 254–271.
Flaherty, D.L., Wilson, L.T., 1999. Biological control of insects and mites on grapes. In: Bellow, T.S., Fisher, T.W. (Eds.), Handbook of Biological Control. Academic Press, New York USA, pp. 853–869.
Fleming, W.E., 1968. Biological control of the Japanese beetle. USDA Technical Bull. 1383, 1–78.
Gale, G., 2003. Saving the vine from phylloxera: a never-ending battle. In: Sandler, M., Pinder, R. (Eds.), Wine: A Scientific Exploration. Taylor and Francis, London, pp. 70–91.
Gaugler, R., Campbell, J.F., Selvan, S., Lewis, E.E., 1992. Large-scale inoculative releases of the entomopathogenic nematode Steinernema glaseri: assessment 50 years later. Biol. Control 2, 181–187.
Gentz, M.C., Murdoch, G., King, G.F., 2010. Tandem use of selective insecticides and natural enemies for effective, reduced-risk pest management. Biol. Control 52, 208–215.
Giese, G., Wolf, T.K., Velasco-Cruz, C., Roberts, L., Heitman, J., 2015. Cover crop and root pruning impacts on vegetative growth crop yield components, and grape composition of Cabernet Sauvignon. Am. J. Enol. Vitic. 66, 212–226.
Gordon, D., Anshelevich, L., Zahavi, T., Ovadia, S., Dunkelbium, E., Harari, A., 2003. Integrating mating disruption techniques against the honeydew moth and the European grapevine moth in vineyards. IOBC WPRS Bull. 26, 131–134.
Granato, D., Margraf, T., Brotzakis, I., Capuano, E., van Ruth, S.M., 2014. Characterization of conventional, biodynamic, and organic purple grape juices by chemical markers antioxidant capacity, and instrumental taste profile. J. Food Sci. 80, C55–C65.
Griffith, C.M., Woodrow, J.E., Seiber, J.N., 2015. Environmental behavior and analysis of agricultural sulfur. Pest Manag. Sci. 71, 1486–1496.
Guerra, B., Steenwerth, K., 2012. Influence of floor management technique on grapevine growth, disease pressure, and juice and wine composition: a review. Am. J. Enol. Vitic. 63, 149–164.
Guerrero, R.F., Cantos-Villar, E., 2015. Demonstrating the efficiency of sulphur dioxide replacements in wine: a parameter review. Trends Food Sci. Technol. 42, 27–43.
Guesmi, B., Serra, T., Kallas, Z., 2012. The productive efficiency of organic farming: the case of grape sector in Catalonia. Span. J. Agric. Res. 10, 552–566.
Guidoni, S., Oggero, G., Cravero, S., Rabino, M., Cravero, M.C., Balsari, P., 2008. Manual and mechanical leaf removal in the bunch zone (*Vitis vinifera* L. cv Barbera): effects on berry composition, health, yield and wine quality, in a warm temperate area. J. Int. Sci. Vigne Vin 42, 49–58.
Hanna, R., Zalom, F.G., Roltsch, W.J., 2003. Relative impact of spider predation and cover crop on population dynamics of *Erythroneura variabilis* in a raisin grape vineyard. Entomol. Exp. Appl. 107, 177–191.
Harari, A.R., Zahavi, T., Gordon, D., Anshelevich, L., Harel, M., Ovadia, S., Dunkelblum, E., 2007. Pest management programs in vineyards using male mating disruption. Pest Manag. Sci. 63, 769–775.
Hildebrandt, A., Guillamón, M., Lacorte, S., Tauler, R., Barceló, D., 2008. Impact of pesticides used in agriculture and vineyards to surface and groundwater quality (North Spain). Water Res. 42, 3315–3326.
Hillier, N.K., Lefebvre, J., 2012. Detection of insect pests of grapes, *Vitis vinifera*, in vineyards of Nova Scotia through pheromone trapping. J. Acad. Entomol. Soc. 8, 30–35.
Ifoulis, A.A., Savopoulou-Soultani, M., 2004. Biological control of *Lobesia botrana* (Lepidoptera: Tortricidae) larvae by using different formulations of *Bacillus thuringiensis* in 11 vine cultivars under field conditions. J. Econ. Entomol. 97, 340–343.
Ingels, C.A., Bugg, R.L., McGourty, G.T., Christensen, L.P., 1998. Cover Cropping in Vineyards: A Grower's Handbook. University of California, pp. 162 (Publication 3338).
Ingels, C.A., Scow, K.M., Whisson, D.A., Drenovsky, R.E., 2005. Effects of cover crops on grapevines yield, juice composition, soil microbial ecology, and gopher activity. Am. J. Enol. Vitic. 56, 19–129.
Iordachescu, A., Moore, A., Iordachescu, G., 2009. Consumer perceptions of organic wine. The Annals of the University Dunarea de Jos of Galati Fascicle VI—Food Technology 34, http://www.researchgate.net/profile/Gabriela_Iordachescu/publication/49614809_Consumer_perceptions_of_organic_wine/links/0912f513f0b3f86785000000.pdf (accessed 26.07.15.).
Isaacs, R., Mercader, R.J., Wise, J.C., 2004. Activity of conventional and reduced-risk insecticides for protection of grapevines against the rose chafer, *Macrodactylus subspinosus* (Coleoptera: Scarabaeidae). J. Appl. Entomol. 128, 371–376.
Jacometti, M.A., Wratten, S.D., Walter, M., 2010. Alternatives to synthetic fungicides for *Botrytis cinerea* management in vineyards. Aust. J. Grape Wine Res. 16, 154–172.

Jenkins, P.E., Isaacs, R., 2007. Cutting wild grapevines as a cultural control strategy for grape berry moth (Lepidoptera: Tortricidae). Environ. Entomol. 36, 187–194.
Jolly, J., Augustyn, O., 2006. The role and use of non-*Saccharomyces* yeasts in wine production. S. Afr. J. Enol. Vitic. 27, 15–39.
Jonsson, M., Wratten, S.D., Landis, D.A., Tompkins, J.M.L., Cullen, R., 2010. Habitat manipulation to mitigate the impacts of invasive arthropod pests. Biol. Invasions 12, 2933–2945.
Jung, R., Schüssler, C., Braunecker, A., 2009. Schraubverschlüsse für Wein: Aufbau und Eigenschaften. Obst- und Weinbau. Schweiz. Z. Obst-Weinbau 20, 6–9.
Jurica, K., Uršulin-Trstenjak, N., Vukić Lušić, D., Lušić, D., Šmit, Z., 2013. Exposure to phtalates and their presence in alcoholic beverages. Arch. Ind. Hyg. Toxicol. 64, 317–325.
Karlsson., P., 2014. The world's grape growing (vineyard) surface area 2000–2012. Consulted January 2016. http://www.bkwine.com/features/winemaking-viticulture/worlds-grape-growing-vineyard-acreage/.
Kast, W.K., 2001. Twelve years of practical experience using mating disruption against *Eupoecilia ambiguella* and *Lobesia botrana* in vineyards of the Wuerttemberg region, Germany. IOBC WPRS Bull. 24, 71–74.
Keller, M., Rogiers, S.Y., Schultz, H.R., 2015. Nitrogen and ultraviolet radiation modify grapevines' susceptibility to powdery mildew. Vitis 42, 87–94.
Kiss, L., Russell, J.C., Szentiványi, O., Xu, X., Jeffries, P., 2004. Biology and biocontrol potential of Ampelomyces mycoparasites: natural antagonists of powdery mildew fungi. Biocontrol Sci. Technol. 14, 635–651.
Koblet, W., Candolfi-Vasconcelos, M.C., Zweifel, W., Howell, G.S., 1994. Influence of leaf removal rootstock, and training system on yield and fruit composition of Pinot noir grapevines. Am. J. Enol. Vitic. 45, 181–187.
Komárek, M., Čadková, E., Chrastný, V., Bordas, F., Bollinger, J.C., 2010. Contamination of vineyard soils with fungicides: a review of environmental and toxicological aspects. Environ. Int. 36, 138–151.
Korosi, G.A., Carmody, B.O., Powell, K.S., 2003. Rootstock screening for phylloxera resistance under controlled conditions using selected phylloxera clonal lineage. Acta Hortic. 904, 53–58.
Krohn, N.G., Ferree, D.C., 2005. Effects of low-growing perennial ornamental groundcovers on the growth and fruiting of seyval blanc grapevines. HortScience 40, 561–568.
Kuflik, T., Prodorutti, D., Frizzi, A., Gafni, Y., Simon, S., Pertot, I., 2009. Optimization of copper treatments in organic viticulture by using a web-based decision support system. Comput. Electron. Agric 68, 36–43.
Lake, C.B., Striegler, R.K., Verdegaal, P.S., Berg, G.T., Wolpert, J.A., 1996. Influence of training system on growth, yield, fruit composition and *Eutypa* incidence of Cabernet Sauvignon grapevines, In:Henick-Kling, T., Wolf, TE, Harkness, E.M. (Eds.), Proceedings for the Fourth International Symposium on Cool Climate Viticulture and Enology. pp. 19–26.
Landis, D.A., Menalled, F.D., Costamagna, A.C., Wilkinson, T.K., 2005. Manipulating plant resources to enhance beneficial arthropods in agricultural landscapes. Weed Sci. 53, 902–908.
Langcake, P., 1981. Disease resistance of *Vitis* spp. and the production of the stress metabolites resveratrol, ε-viniferin, α-viniferin and pterostilbene. Physiol. Plant Pathol. 18, 213–226.
Lentini, A., Serra, G., Ortu, S., Delrio, G., 2008. Seasonal abundance and distribution of *Planococcus ficus* on grape vine in Sardinia. IOBC/WPRS Bull. 36, 267–272.
Leroux, P., Fritz, R., Debieu, D., Albertini, C., Lanen, C., Bach, J., Chapeland, F., 2002. Mechanisms of resistance to fungicides in field strains of *Botrytis cinerea*. Pest Manag. Sci. 58, 876–888.
Lotter, D.W., Granett, J., Omer, A.D., 1999. Differences in grape phylloxera-related grapevine root damage in organically and conventionally managed vineyards in California. HortScience 34, 1108–1111.
Macey, A., 2010. Certified Organic Production Statistics for Canada 2008. Canadian Organic Growers. 8 p. https://www.cog.ca/uploads/Certified%20Organic%20Statistics%20Canada%202008.pdf (accessed 29.07.15.).
Macey, A., 2011. Certified organic production statistics for Canada 2009. Can. Org. Grow. Agric. Agri-Food Can. (8 p.).
Macey, A., 2012. Canadian organic production statistics. Can. Org. Grow. (8 p.).
Mackie, K.A., Müller, T., Zikeli, S., Kandeler, E., 2013. Long-term copper application in an organic vineyard modifies spatial distribution of soil micro-organisms. Soil Biol. Biochem. 65, 245–253.
Mani, M., Shivaraju, C., Kulkarni, N.S., 2014. Biopesticides and biocontrol agents used in vineyards. In: The Grape Entomology. Springer, India, pp. 175–179.
Mannini, F., 2007. Hot water treatment and field coverage of mother plant vineyards to prevent propagation material from phytoplasma infections. Bull. Insectol. 60, 311–312.
Marshall, D.B., Lester, P.J., 2001. The transfer of *Typhlodromus pyri* on grape leaves for biological control of *Panonychus ulmi* (Acari: Phytoseiidae Tetranychidae) in vineyards in Ontario. Can. Biol. Control 20, 228–235.
Martin, K.R., Rasmussen, K.K., 2011. Comparison of sensory qualities of geographically paired organic and conventional red wines from the southwestern US with differing total polyphenol concentrations: a randomized pilot study. Food Nutr. Sci. 02, 1150–1159.
Martins, V., Teixeira, A., Bassil, E., Blumwald, E., Gerós, H., 2014. Metabolic changes of *Vitis vinifera* berries and leaves exposed to Bordeaux mixture. Plant Physiol. Biochem. 82, 270–278.
Mazzoni, E., Colla, R., Chiusa, B., Ciampitti, M., Cravedi, P., 2003. Experiences for vector control of grape golden flavescence in Lombardia and Emilia Romagna (Northern Italy) vineyards. IOBC WPRS Bull. 26, 221–226.
McGourty, G.T., Reganold, J.P., 2005. Managing vineyard soil organic matter with cover crops, In: Smart, D.R., Christensen, P. (Eds) Proceeding of the Soil Environment and Vine Mineral Nutrition Symposium, pp. 145–151.
Meeker, J.D., Sathyanarayana, S., Swan, S.H., 2009. Phthalates and other additives in plastics: human exposure and associated health outcomes. Biol. Sci. 364, 2097–2113.
Miele, A., Rizzon, L.A., Queiroz, S.C.D.N., de Gianello, C., 2015. Physicochemical composition, minerals, and pesticide residues in organic grape juices. Food Sci. Technol. 35, 120–126.
Millar, J.G., Daane, K.M., Mcelfresh, J.S., Moreira, J.A., Malakar-Kuenen, R., Guillén, M., Bentley, W.J., 2002. Development and optimization of methods for using sex pheromone for monitoring the mealybug *Planococcus ficus* (Homoptera: Pseudococcidae) in California vineyards. J. Econ. Entomol. 95, 706–714.
Mills, N., Daane, K., 2005. Biological and cultural controls. Nonpesticide alternatives can suppress crop pests. Calif. Agric. 59, 23–28.
Molitor, D., Behr, M., Hoffmann, L., Evers, D., 2012. Impact of grape cluster division on cluster morphology and bunch rot epidemic. Am. J. Enol. Vitic. 63, 508–514.
Molitor, D., Baron, N., Sauerwein, T., André, C.M., Kicherer, A., Döring, J., Evers, D., 2015. Postponing first shoot topping reduces grape cluster compactness and delays bunch rot epidemic. Am. J. Enol. Vitic. 66, 164–176.
Moreau, J., Benrey, B., Thiéry, D., 2006. Grape variety affects larval performance and also female reproductive performance of the European grapevine moth *Lobesia botrana* (Lepidoptera: Tortricidae). Bull. Entomol. Res. 96, 205–212.
Morlat, R., Jacquet, A., 2003. Grapevine root system and soil characteristics in a vineyard maintained long-term with or without interrow sward. Am. J. Enol. Vitic 54, 1–7.
Moschos, T., Souliotis, C., Broumas, T., Kapothanassi, V., 2004. Control of the European grapevine moth *Lobesia botrana* in Greece by the mating disruption technique: a three-year survey. Phytoparasitica 32, 83–96.
Mulero, J., Pardo, F., Zafrilla, P., 2009. Effect of principal polyphenolic components in relation to antioxidant activity in conventional and organic red wines during storage. Eur. Food Res. Technol. 229, 807–812.
Mulero, J., Pardo, F., Zafrilla, P., 2010. Antioxidant activity and phenolic composition of organic and conventional grapes and wines. J. Food Compos. Anal. 23, 569–574.
Mundy, D.C., Agnew, R.H., Wood, P.N., 2012. Grape tendrils as an inoculum source of *Botrytis cinerea* in vineyards—a review. N. Z. Plant Prot. 65, 218–227.
Murphy, B.C., Rosenheim, J.A., Dowell, R.V., Granett, J., 1998. Habitat diversification tactic for improving biological control: parasitism of the western grape leafhopper. Entomol. Exp. Appl. 87, 225–235.
Núñez-Delicado, E., Sánchez-Ferrer, A., García-Carmona, F.F., López-Nicolás, J.M., 2005. Effect of organic farming practices on the level of latent polyphenol oxidase in grapes. J. Food Sci. 70, C74–C78.
Nagarkatti, S., Tobin, P.C., Saunders, M.C., Muza, A.J., 2003. Release of native Trichogramma minutum to control grape berry moth. Can. Entomol. 135, 589–598.
Nash, M.A., Hoffmann, A.A., Thomson, L.J., 2010. Identifying signature of chemical applications on indigenous and invasive nontarget arthropod communities in vineyards. Ecol. Appl. 20, 1693–1703.
Nicholls, C.I., Parrella, M.P., Altieri, M.A., 2000. Reducing the abundance of leafhoppers and thrips in a northern California organic vineyard through maintenance of full season floral diversity with summer cover crops. Agric. Forest Entomol. 2, 107–113.
Nicholls, C.I., Parrella, M., Altieri, M.A., 2001. The effects of a vegetational corridor on the abundance and dispersal of insect biodiversity within a northern California organic vineyard. Landsc. Ecol. 16, 133–146.
Ogbeide, O.A., 2015. Consumer willingness to pay a premium for organic wine: discriminant analysis. J. Agribus. 1, 24–42.
Pérès, G., Cluzeau, D., Curmi, P., Hallaire, V., 1998. Earthworm activity and soil structure changes due to organic enrichments in vineyard systems. Biol. Fertil. Soils 27, 417–424.
Palliotti, A., 2012. A new closing Y-shaped training system for grapevines. Aust. J. Grape Wine Res. 18, 57–63.
Pedneault, K., Provost, C., 2016. Fungus resistant grape varieties as a suitable alternative for organic wine production: benefits, current knowledge, and challenges. Sci. Hortic., http://dx.doi.org/10.1016/j.scienta.2016.03.016 (in press).
Percival, D.C., Sullivan, J.A., Fisher, K.H., 1993. Effect of cluster exposure, berry contact and cultivar on cuticular membrane formation and occurrence of bunch rot (*Botrytis cinerea* Pers.: Fr.) with 3 *Vitis vinifera* L. cultivars. Vitis 32, 87–97.
Peverieri, G.S., Simoni, S., Goggioli, D., Liguori, M., Castagnoli, M., 2009. Effects of variety and management practices on mite species diversity in Italian vineyards. Bull. Insectol. 62, 53–60.
Pezet, R., Viret, O., Perret, C., Tabacchi, R., 2003. Latency of *Botrytis cinerea* Pers. Fr. and biochemical studies during growth and ripening of two grape berry cultivars, respectively susceptible and resistant to grey mould. J. Phytopathol. 151, 208–214.
Pimentel, D., Acquay, H., Biltonen, M., Rice, P., Silva, M., Nelson, J., D'amore, M., 1992. Environmental and economic costs of pesticide use. BioScience 42, 750–760.
Plana, 2013. Situations particulières conduisant à des contaminations inattendues par des résidus de pesticides, In: Laboratoire Excell, Pesticides dans les Vins: Etat des lieux, Stratégie de Réduction au Vignoble et Nouvelles Perspectives, Bordeaux-Lac, France. (pp. 58–75) http://www.labexcell.com/pesticides-dans-les-vins/ (accessed 15.07.15.).

Powell, K.S., Burns, A., Norng, S., Granett, J., McGourty, G., 2007. Influence of composted green waste on the population dynamics and dispersal of grapevine phylloxera *Daktulosphaira vitifoliae*. Agric. Ecosyst. Environ. 119, 33–38.
Provenzano, M.R., Bilali El, H., Simeone, V., Baser, N., Mondelli, D., Cesari, G., 2010. Copper contents in grapes and wines from a Mediterranean organic vineyard. Food Chem. 122, 1338–1343.
Pscheidt, J.W., Pearson, R.C., 1989. Effect of grapevine training systems and pruning practices on occurrence of Phomopsis cane and leaf spot. Plant Dis. 73, 825–828.
Putman, A.R., DeFrank, J., Barnes, J.O., 1986. Exploitation of allelopathy for weed control in annual and perennial cropping systems. J. Chem. Ecol. 9, 1001–1010.
Reynier, A., 2012. Manuel de Viticulture, 11 edition. Lavoisier, Paris, pp. 592.
Reynolds, A.G., Vanden Heuvel, J.E., 2009. Influence of grapevine training systems on vine growth and fruit composition: a review. Am. J. Enol. Vitic. 60, 251–268.
Reynolds, A.G., 2008. Grapevine canopy management. In: Wolf, T.K. (Ed.), Wine Grape, Production Guide for Eastern North America. Plant and life sciences publishing, New York, pp. 124–134.
Rodrigues, A.D., Scheffel, T.B., Scola, G., Santos, M.T.D., Fank, B., de Freitas, S.C.V., Dani, C., Vanderlinde, R., Henriques, J.A.P., Coitinho, A.S., Salvador, M., 2012. Neuroprotective and anticonvulsant effects of organic and conventional purple grape juices on seizures in Wistar rats induced by pentylenetetrazole. Neurochem. Int. 60, 799–805.
Roehrich, R., Carles, J.P., Tresor, C., De Vathaire, M.A., 1979. Essais de confusion sexuelle contre les tordeuses de la grappe: l'eudemis *Lobesia botrana* Den. et Schiff. et la cochylis *Eupoecilia ambiguella* Hb. Ann. Zool. Ecol. Anim. 11, 659–675.
Rojas-Méndez, J.I., Le Nestour, M., Rod, M., 2015. Understanding attitude and behavior of canadian consumers toward organic wine. J. Food Prod. Market. 21, 375–396.
Rombourgh, L., 2002. The Grape Grower A Guide to Organic Viticulture. Chelsea Green Publishing, Vermont, USA, pp. 290 p.
Rosenquist, J.K., Morrison, J.C., 1989. Some factors affecting cuticle and wax accumulation on grape berries. Am. J. Enol. Vitic. 40, 241–244.
Rousseau, J., 1997. Flavescence dorée: what can be done organically? Agric. Biol. 11, 20–23.
Russo, M.V., Notardonato, I., Cinelli, G., Avino, P., 2012. Evaluation of an analytical method for determining phthalate esters in wine samples by solid-phase extraction and gas chromatography coupled with ion-trap mass spectrometer detector. Anal. Bioanal. Chem. 402, 1373–1381.
Sanguankeo, P.P., León, R.G., 2011. Weed management practices determine plant and arthropod diversity and seed predation in vineyards. Weed Res. 51, 404–412.
Sanguankeo, P.P., Leon, R.G., Malone, J., 2009. Impact of weed management practices on grapevine growth and yield components. Weed Sci. 57, 103–107.
Savage, S., Ann Sall, M., 1982. Vineyard cultural practices may help reduce botrytis bunch rot. Calif. Agric. 36, 8–9.
Savage, S.D., Sall, M.A., 1984. Botrytis bunch rot of grapes: influence of trellis type and canopy microclimate. Phytopathology 74, 65–70.
Savocchia, S., Stummer, B.E., Wicks, T.J., Van Heeswijck, R., Scott, E.S., 2004. Reduced sensitivity of Uncinula necator to sterol demethylation inhibiting fungicides in southern Australian vineyards. Aust. Plant Pathol. 33, 465–473.
Scarratt, S.L., 2005. Enhancing the Biological Control of Leafrollers (Lepidoptera: Tortricidae) Using Floral Resource Subsidies in an Organic Vineyard in Marlborough, New Zealand. Doctoral Dissertation. Lincoln University, New Zealand, pp. 120 p.
Schmidt-Tiedemann, A., Louis, F., Fukumoto, T., Zebitz, C.P., Arn, H., 1999. Mating disruption tests to control sparganothis pilleriana (Schiff.) (Lepidoptera: Tortricidae). IOBC WPRS Bull. 22, 77–82.
Serra, G., Lentini, A., Verdinelli, M., Delrio, G., 2006. Effects of cover crop management on grape pests in a Mediterranean environment. IOBC WPRS Bull. 29, 209–214.
Sharley, D.J., Hoffmann, A.A., Thomson, L.J., 2008. The effects of soil tillage on beneficial invertebrates within the vineyard. Agric. Forest Entomol. 10, 233–243.
Sharon, R., Zahavi, T., Soroker, V., Harari, A.R., 2009. The effect of grape vine cultivars on *Lobesia botrana* (Lepidoptera: Tortricidae) population levels. J. Pest Sci. 82, 187–193.
Sholberg, P.L., Boulé, J., 2006. Efficacy of mineral clay for control of powdery mildew and leafhoppers on grapes, 1999. Biological Cult. Tests 16, N60. In: Serra, G., Lentini, A., Verdinelli, M., Delrio, G. (Eds.), Effects of Cover Crop Management on Grape Pests in a Mediterranean Environment, 29. IOBC WPRS Bulletin, pp. 209–214.
Sivčev, B.V., Sivčev, I.L., Rankovic-Vasic, Z.Z., 2010. Natural process and use of natural matters in organic viticulture. J. Agric. Sci. 55, 195–215.
Smart, R.E., 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality. Am. J. Enol. Vitic. 36, 230–239, A review.
Spayd, S.E., Tarara, J.M., Mee, D.L., Ferguson, J.C., 2002. Separation of sunlight and temperature effects on the composition of *Vitis vinifera* cv. Merlot berries. Am. J. Enol. Vitic. 53, 171–182.
Stavrinides, M.C., Daane, K.M., Lampinen, B.D., Mills, N.J., 2010. Plant water stress, leaf temperature, and spider mite (Acari: Tetranychidae) outbreaks in California vineyards. Environ. Entomol. 39, 1232–1241.
Sweet, R.M., Schreiner, R.P., 2010. Alleyway cover crops have little influence on Pinot noir grapevines (*Vitis vinifera* L.) in two western Oregon vineyards. Am. J. Enol. Vitic. 61, 240–252.
Tapio, E., Pohto-Lahdenperä, A., 1991. Scanning electron microscopy of hyphal interaction between *Streptomyces griseoviridis* and some plant pathogenic fungi. J. Agric. Sci. Finl. 63, 435–441.
Tardaguila, J., de Toda, F.M., Poni, S., Diago, M.P., 2010. Impact of early leaf removal on yield and fruit and wine composition of *Vitis vinifera* L. Graciano and Carignan. Am. J. Enol. Vitic. 61, 372–381.
Taschenberg, E.F., Cardé, R.T., Roelofs, W.L., 1974. Sex pheromone mass trapping and mating disruption for control of redbanded leafroller and grape berry moths in vineyards. Environ. Entomol. 3, 239–242.
Tassoni, A., Tango, N., Ferri, M., 2013. Comparison of biogenic amine and polyphenol profiles of grape berries and wines obtained following conventional, organic and biodynamic agricultural and oenological practices. Food Chem. 139, 405–413.
Tesic, D., Keller, M., Hutton, R.J., 2007. Influence of vineyard floor management practices on grapevine vegetative growth yield, and fruit composition. Am. J. Enol. Vitic. 58, 1–11.
Thies, C., Tscharntke, T., 1999. Landscape structure and biological control in agroecosystems. Science 285, 893–895.
Thomas, C.S., Marois, J.J., English, J.T., 1988. The effects of wind speed temperature, and relative humidity on development of aerial mycelium and conidia of Botrytis cinerea on grape. Phytopathology 78, 260–265.
Thomson, L.J., Hoffmann, A.A., 2007. Effects of ground cover (straw and compost) on the abundance of natural enemies and soil macro invertebrates in vineyards. Agric. Forest Entomol. 9, 173–179.
Tivoli, B., Calonnec, A., Richard, B., Ney, B., Andrivon, D., 2013. Current knowledge on plant/canopy architectural traits that reduce the expression and development of epidemics. Eur. J. Plant Pathol. 135, 471–478.
Trimble, R.M., Vickers, P.M., Nielsen, K.E., Barinshteyn, G., 2003. Sprayable pheromone for controlling the North American grape berry moth by mating disruption. Agric. Forest Entomol. 5, 263–268.
Tubajika, K.M., Civerolo, E.L., Puterka, G.J., Hashim, J.M., Luvisi, D.A., 2007. The effects of kaolin harpin, and imidacloprid on development of Pierce's disease in grape. Crop Prot. 26, 92–99.
USDA, 2015a. USDA, 2015. Certified organic and total U.S acreage, selected crops and livestock, 1995–2011. USDA Economic Research Service.
USDA, 2015. Agriculture: National Organic Program. Online: http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title07/7cfr205_main_02.tpl (accessed 25.07.15.).
Vail, M.E., Marois, J.J., 1991. Grape cluster architecture and the susceptibility of berries to *Botrytis cinerea*. Phytopathology 81, 188–191.
Valizadeh, H., Abbasipour, H., Farazmand, H., Askarianzadeh, A., 2013. Evaluation of kaolin application on oviposition control of the Vine Cicada, *Psalmocharias alhageos* in Vineyards (Homoptera: Cicadidae). Entomol. Ger. 34, 279–286.
Varner, M., Lucin, R., Mattedi, L., Forno, F., 2001. Experience with mating disruption technique to control grape berry moth, *Lobesia botrana*, in Trentino. IOBC WPRS Bull. 24, 81–88.
Verdenal, T., Zufferey, V., Spring, J.L., Viret, O., 2013. Conséquences physiologiques de l'effeuillage de la vigne: revue de littérature. Rev. Suisse Vitic. Arboric. Hortic. 45, 148–155.
Vincent, C., Hallman, G., Panneton, B., Fleurat-Lessard, F., 2003. Management of agricultural insects with physical control methods. Ann. Rev. Entomol. 48, 261–281.
Walton V.M., Pringle K.L., 2002. Evaluating effectiveness of mass releases of the vine mealybug (*Planococcus ficus*) parasitoid *Coccidoxenoides peregrinus* in Western Cape Province vineyards, South Africa. In: Proceedings of the First International Symposium on Biological Control of Arthropods, Honolulu, Hawaii, USA. 14–18.
Walton, V.M., Daane, K.M., Pringle, K.L., 2004. Monitoring *Planococcus ficus* in South African vineyards with sex pheromone-baited traps. Crop Prot. 23, 1089–1096.
Walton, V.M., Daane, K.M., Bentley, W.J., Millar, J.G., Larsen, T.E., Malakar-Kuenen, R., 2006. Pheromone-based mating disruption of *Planococcus ficus* (Hemiptera: Pseudococcidae) in California vineyards. J. Econ. Entomol. 99, 1280–1290.
Walton, V.M., Dalton, D.T., Daane, K.M., Kaiser, C., Hilton, R.J., 2013. Seasonal phenology of *Pseudococcus maritimus* (Hemiptera: Pseudococcidae) and pheromone-baited trap survey of four important mealybug species in three wine grape growing regions of oregon. Ann. Entomol. Soc. Am. 106, 471–478.
Wheaton, A.D., McKenzie, B.M., Tisdall, J.M., 2008. Management to increase the depth of soft soil improves soil conditions and grapevine performance in an irrigated vineyard. Soil Till. Res. 98, 68–80.
Wheeler, S.J., Black, A.S., Pickering, G.J., 2005. Vineyard floor management improves wine quality in highly vigorous *Vitis vinifera*' Cabernet Sauvignon' in New Zealand. N. Z. J. Crop Hortic. 33, 317–328.
Willer, H., Lernoud, J., 2014. The World of Organic Agriculture. Statistics and Emerging Trends 2014. FiBL-IFOAM Report. Research Institute of Organic Agriculture(FiBL), Frick, and IFOAM-Organics International, Bonn, Germany308.
Willer, H., Lernoud, J., 2015. The World of Organic Agriculture. Statistics and Emerging Trends 2015. FiBL-IFOAM Report. Research Institute of Organic Agriculture(FiBL), Frick, and IFOAM-Organics International, Bonn306.
Willer, H., Yussefi, M., 2006. The World of Organic Agriculture. Statistics and Emerging Trends 2006. FiBL-IFOAM Report. Research Institute of Organic Agriculture (FiBL), Frick, and IFOAM-Organics International, Bonn, Germany215.
Willer, H., Yussefi, M., Sorensen, N., 2008. The World of Organic Agriculture. Statistics and Emerging Trends 2008. IFOAM, Bonn and FiBL, Frick. Hardcover edition, Earthscan London.

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Willer, H., 2008. Organic Viticulture in Europe: Development and Current Statistics. 16th IFOAM Organic Congress, Modena, Italy, pp. 16–20 (June).
Wisler, G.C., Norris, R.F., 2005. Interactions between weeds and cultivated plants as related to management of plants as related to management of plant pathogens. Weed Sci. 53, 914–917.
Witzgall, P., Kirsch, P., Cork, A., 2010. Sex pheromones and their impact on pest management. J. Chem. Ecol. 36, 80–100.
Wold-Burkess, S., 2011. Japanese beetle. In: Hoover, E., Wold-Burkness, S., Hilton, J., Mollov, D., Burkness, E., Galvan, T., Hemstad, P., Hutchinson, W.D. (Eds.), Grape PM Guide for Minnesota Producers. University of Minnesota: St. Paul, MN USA, pp. 44–45.
Yasnosh, V., Rtskhiladze, M., Tabatadze, E., 2001. Coccids (Hemiptera, Coccinea) and their natural enemies in the vineyards of Georgia: present situation. Boll. Zool. Agrar. Bachi. 33, 351–355.
Yildirim, H.K., Akçay, Y.D., Güvenç, U., Sözmen, E.Y., 2004. Protection capacity against low-density lipoprotein oxidation and antioxidant potential of some organic and non-organic wines. Int. J. Food Sci. Nutr. 55, 351–362.
Yildirim, H.K., Üren, A., Yücel, U., 2007. Evaluation of biogenic amines in organic and non-organic wines by HPLC OPA derivatization. Food Technol. Biotechnol. 45, 62–68.
Zabadal, T.J., Dittmer, T.W., 1998. Vine management systems affect yield, fruit quality, cluster compactness, and fruit rot of Chardonnay grape. HortScience 33, 806–809.
Zahavi, T., Reuveni, M., 2012. Effect of grapevine training systems on susceptibility of berries to infection by Erysiphe necator. Eur. J. Plant Pathol. 133, 511–515.
Zahavi, T., Reuveni, M., Scheglov, D., Lavee, S., 2001. Effect of grapevine training systems on development of powdery mildew. Eur. J. Plant Pathol. 107, 495–501.
Zehnder, G., Gurr, G.M., Kühne, S., Wade, M.R., Wratten, S.D., Wyss, E., 2007. Arthropod pest management in organic crops. Ann. Rev. Entomol. 52, 57–80.
da Costa, A., Delgadillo, I., Rudnitskaya, A., 2014. Detection of copper lead, cadmium and iron in wine using electronic tongue sensor system. Talanta 129, 63–71.

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