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MECHANICAL BEHAVIOUR OF GRAPEVINE WOOD AFFECTED BY *Xylotrechus arvicola*

Álvaro Rodríguez-González[1,♠]

https://orcid.org/0000-0002-2117-593X

Pedro A. Casquero[1]

https://orcid.org/0000-0002-4432-9794

José A. Pereira[2]

https://orcid.org/0000-0002-2260-0600

Óscar González-López[3]

https://orcid.org/0000-0002-6004-9653

Marcos Guerra[4]

https://orcid.org/0000-0001-7504-9595

Julia García-González[5]

https://orcid.org/0000-0002-8972-1861

Julia M. Morán-Del Pozo[5]

https://orcid.org/0000-0001-8768-5898

Andrés Juan-Valdés[5]

https://orcid.org/0000-0003-0902-6429

ABSTRACT

The cerambycid insect *Xylotrechus arvicola* is considered a pest that affects the wood of the grapevine (*Vitis vinifera*) in the major wine areas of the Iberian Peninsula. The larva of this insect perforates the grapevine wood, resulting in structural and biomechanical failure of the vine plants. Vine samples from wood damaged by *X. arvicola* larvae were picked up from different vineyards and grape varieties. Compressive and flexural tests were performed in order to assess the mechanical behaviour of the wood samples. Total length of the cracks in wood samples (TLCWS) that appeared on the surface of the grapevine wood samples after the mechanical tests was measured. Compressive strength (CS) and flexural strength (FS) decreased with the increase of the cross-sectional area (CSA) of both branches and trunks, regardless of damage condition or water content. Moreover, the resistance was lower in damaged wood. In addition, this was verified through the linear regression coefficients of the interaction CS x CSA and FS x CSA. TLCWS in branches and trunks of

[1]Universidad de León. Escuela de Ingeniería Agraria y Forestal (EIAF). Instituto de Medio Ambiente, Recursos Naturales y Biodiversidad (INMARENBIO). Grupo Universitario de Investigación en Ingeniería y Agricultura Sostenible (GUIIAS). León, España.

[2]Instituto Politécnico de Bragança (IPB). Centro de Investigação de Montanha (CIMO). Escola Superior Agraria (ESA). Bragança, Portugal.

[3]Universidad de La Rioja. Complejo Científico Tecnológico. Departamento de Agricultura y Alimentación. Área de Producción Vegetal. Logroño, España.

[4]Universidad de León. Escuela de Ingeniería Agraria y Forestal (EIAF). Grupo Universitario de Investigación en Ingeniería y Agricultura Sostenible (GUIIAS). Ponferrada, España.

[5]Universidad de León. Escuela de Ingeniería Agraria y Forestal (EIAF). Grupo de Investigación en Ingeniería de Materiales y Eco-Eficiencia (INMATECO). León, España.

♠Corresponding author: alrog@unileon.es

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damaged samples was greater that in undamaged samples. Also, TLCWS within the same damage condition and part of the plant was higher in dry samples than in fresh samples. The damaged wood would show a higher vulnerability to common mechanical stress suffered by the grapevines in the field including heavy winds, fruit overweight or harvesting machines shaking (when mechanically collected). Larvae of this insect altered the mechanical behaviour of the trunk and branches of grapevine wood. The mechanical strength of wood was more negatively affected when the CSA of the branches and trunks increased. Longer TLCWS was found in affected wood.

Keywords: Crack length, compressive strength, diameter, flexural strength, larvae borer, vineyard.

INTRODUCTION

Insects are one of the most important causes of damage in woody crops (Sen *et al.* 2017), this resulting in significant economic losses (Ssemaganda *et al.* 2011). Wood boring beetles cause irreversible damage to forests, crops, and timber (Visitpanich 1994, Aukema *et al.* 2011). Woody plant species, like grapevines, are sensitive to being attacked by wood boring insects. There are insects among the European species, both polyphagous and monophagous, attacking different woody plant species (Svacha and Danilevsky 1988, Sama 2002).

Xylotrechus arvicola (Coleoptera: Cerambycidae) is a xylophagous polyphagous wood-boring insect that attack on riverside trees such us *Quercus* spp., *Carpinus* spp. and *Castanea* spp. (Bahillo 1996, Vives 2000, Moreno 2005, Biurrun *et al.* 2007). This insect is also an important pest of grapevines (*Vitis vinifera*) in the major wine areas in the Iberian Peninsula (Ocete and Del Tío 1996, Rodríguez and Ocaña 1997, Ocete and López 1999, Peláez *et al.* 2001, Ocete *et al.* 2002a). *X. arvicola* is not the only species described as a pest attacking vines. *Trogoxylon impressum* Comolli (Coleoptera: Lyctidae), *Xyloperthodes incertus* Lesne (Coleoptera: Bostrichidae) and *Acalolepta vastator* Newman (Coleoptera: Cerambycidae) are also wood-boring insect species described as vineyards pests (Goodwin and Pettit 1994, Halperin and Geis 1999, Allsopp and Knipe 2004). *X. arvicola* adults measure 8 mm to 20 mm in length, being females on average larger than males. Its coloration is brown or blackish, while the pronotal and elytral bands are usually yellow (Moreno *et al.* 2003). Female *X. arvicola* lay eggs concentrated in cracks or under the vine rhytidome (Peláez *et al.* 2002). The oviposition is extended over a long period of time (Rodríguez-González *et al.* 2016a, Rodríguez-González *et al.* 2017a) and, about 8 days after the egg laying, the larvae emerge (Rodríguez-González *et al.* 2016b). Larvae move into the wood, boring galleries inside the plant (García-Ruiz 2009). The most fragile stages are adults, eggs, and neonate larvae. The larvae, once inserted in the wood, are inaccessible when applying traditional chemicals (Peláez *et al.* 2002) which do not have penetrative attributes (Rodríguez-González *et al.* 2017b).

The damage to grapevines wood is caused by larvae which perforate grapevine plants to feed on wood, making galleries within the plant for two years (Moreno 2005). Previous studies carried out with wood samples simulating the load conditions that vine wood bears on the field have shown that the vine wood affected by larvae is more sensitive to breakage and it breaks faster than undamaged wood (Rodríguez-González *et al.* 2019, Rodríguez-González *et al.* 2020). Other indirect damage is produced by adults emerging from holes, which are a direct infection access points for fungal diseases such us *Diplodia seriata* (De Not), *Eutypa lata* (Tul and Tul) or *Phaeoacremonium minimun* (Gams, Crous, Wingf., Mugnai) (García-Benavides *et al.* 2013). ´Tempranillo´ and ´Cabernet-Sauvignon´ varieties have a greater sensitivity to being attacked by *X. arvicola* (Ocete *et al.* 2002a, García-Benavides *et al.* 2013). In an affected vineyard, numerous broken branches could be seen due to a weakened wood structure caused by the galleries bored by larvae (García-Ruiz 2009). The only current cultural techniques available to control *X. arvicola* consist of removing the rhytidome of the grapevines (Peláez *et al.* 2006) or/and pruning branches below the affected area (Ocete *et al.* 2004), but these techniques are expensive and not sustainable (Peláez *et al.* 2006).

The present study would allow to estimate wood resistance under natural loads or/and under physical events that affect vineyards (wind, grape bearing, mechanical harvest) and the reduction in wood resistance of a grapevine affected by *X. arvicola* larvae.

Therefore, the objective of this study was to examine the mechanical behaviour of grapevine wood from trunks and branches affected by *X. arvicola* larvae using wood samples with different section area and from different *V. vinifera* varieties. Also, the total length of the cracks that appeared in the wood samples (TLCWS) after performing the mechanical tests was measured.

MATERIALS AND METHODS

Materials

Grapevine wood samples

Grapevine wood samples (trunks and branches) of all three varieties infested with *X. arvicola* larvae or uninfested samples were randomly chosen to test the mechanical performance of wood.

Samples grouped by variety were then sorted into damaged or undamaged material according to external damage (galleries in pruning cuts and/or exit holes of adults and larval galleries on ends of samples) as described by Peláez *et al.* (2006).

Samples were collected from three severe pruned vineyards to rebuild the plant structure and avoid *X. arvicola* spreading, in 2017 and 2018 seasons. Two vineyards, located in 'Ribera Del Duero' (Peñafiel; Valladolid) and 'León' (Gordoncillo; León), both Protected Designation of Origin (PDO) in Castilla y Leon, Spain, were used for sampling. Sampled varieties in Peñafiel were 30-year-old ´Tempranillo´ and 32-year-old ´Cabernet-Sauvignon´ growing in loam-sandy soils. The sampled variety in Gordoncillo was 27-year-old ´Prieto Picudo´ growing in clay-loam texture soil. The vines in both locations, were spaced 3 m × 1,5 m. The vines trained into ´Trellis´ system, were consisted of two branches (1,0 m length each) and a trunk (0,7 m height).

Methods

Experimental conditions before mechanical tests were performed

Before mechanical tests Structural Round Timber Test Methods (EN 14251-2003), were used to choose only samples with the appropriate measurements to be analysed. Measurements from the diameter and length of both branches and trunks were taken for all the samples according to the EN 14251-2003. Rest of samples that does not fall in testing category according to EN 14251-2003 were discarded.

Eleven wood samples of ´Tempranillo´ and eight wood samples of ´Cabernet-Sauvignon´ varieties were evaluated when they were green so that water content of the samples was close to the one in the vineyard. However, the wood of the ´Prieto Picudo´ variety, could not be evaluated in fresh conditions because when collected it was dry. Moisture contents of the selected samples were determined as described in EN 14251-2003. Samples were dried to remove moisture from wood according to method described in Rodríguez-González *et al*. 2019 and Rodríguez-González *et al*. 2020. Ten samples of ´Tempranillo´ and ´Cabernet-Sauvignon´ varieties were dried and moisture contents were measured using Equation 1.

$$\mathrm{WC} = \frac{\mathrm{FS} - \mathrm{DS}}{\mathrm{DS}}\ x\ 100 \quad (1)$$

Where:

WC: Water Content (%); FS: Fresh Sample (g); DS: Dry Sample (g).

Mechanical strength of grapevine wood samples

Two standard strength experiments: compressive tests for wood trunks and flexural tests for branches were performed in order to analyse the mechanical behaviour of grapevine wood, from selected *V. vinifera* varieties, damaged by *X. arvicola* larvae.

All grapevine samples, undamaged or damaged, fresh or dry, were tested with a hydraulic press (Figure 2a) according to the methodology described by Rodríguez-González *et al.* 2019, Rodríguez-González *et al.* 2020.

Test 1: Compressive strength (CS) of grapevine trunks in relation to cross sectional area (CSA)

Dimensions of trunks samples (fresh and dry) were measured before testing by adopting method described by Rodríguez-González *et al.* 2019, Rodríguez-González *et al.* 2020.

The existence of galleries and the number of adult exit holes on both ends of the sample were recorded for the damaged wood trunks samples.

Vertically placed trunks were used to simulate the compressive strength suffered by the vine trunks in field conditions, with both end surfaces cut perpendicularly to the axis of the sample (Figure 1a).

The compressive test was performed according to EN 14251-2003 so the Equation 2, Equation 3, Equation 4, Equation 5, Equation 6 were considered for the analysis:

$$\lambda = \frac{lk}{i} \quad (2)$$

$$i = \sqrt{\frac{I}{A}} \quad (3)$$

$$I = \frac{\pi r^4}{4} \quad (4)$$

$$A = \pi r^2 \quad (5)$$

$$\sigma = \frac{N}{A} = \frac{N}{\pi r^2} \quad (6)$$

Where λ : slenderness ratio (dimensionless); lk: buckling length of the sample (mm); i: radius of gyration (mm); I: area moment of inertia (mm^4); A: cross sectional area (mm^2); r: radius (mm); σ: compressive normal stress (MPa); N: normal force (N).

Test 2: Flexural strength (FS) of grapevine wood branches in relation to cross sectional area (CSA)

Before the mechanical strength was performed, different dimensions were measured in every of the branch samples (fresh and dry) according to the methodology described by Rodríguez-González *et al.* 2019, Rodríguez-González *et al.* 2020.

The existence of galleries and the number of adult exit holes on both ends of the sample were recorded for the damaged wood branches samples.

The branches, placed horizontally, rested in two roller supports 30 cm apart. Two concentrated loads were applied from the topside of the wood sample (four point bending test), to simulate the downward bending suffered by the vine branches in field conditions (Figure 1b).

The flexural test was performed EN 14251-2003 and the Equation 7, Equation 8, Equation 9 and Equation 10 were considered for the analysis:

$$i = \sqrt{\frac{I}{A}} \quad (7)$$

$$I = \frac{\pi r^4}{4} \quad (8)$$

$$A = \pi r^2 \quad (9)$$

$$\acute{o} = \frac{M_Z}{W_Z} = \left(\frac{M_Z}{I}\right) r \quad (10)$$

Where i: radius of gyration (mm); I: area moment of inertia (mm^4); A: cross sectional area (mm^2); r: radius (mm); σ: normal stress from bending (MPa); Mz: bending moment (N·mm); Wz: section modulus (mm^3).

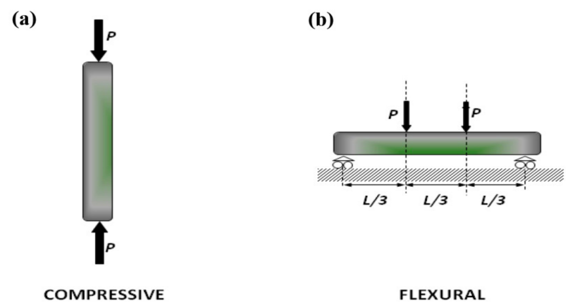

Figure 1: (a) Load diagram for compressive tests in grapevine trunks (P uniaxial forces were applied by a constant load speed of 200 N/s up to failure); (b) Load diagrams for flexural tests in grapevine branches (the two P forces were applied in the central third of the sample by a constant load speed of 200 N/s up to failure. ´i´, and ´ii´ were the roller supports of the wood samples).

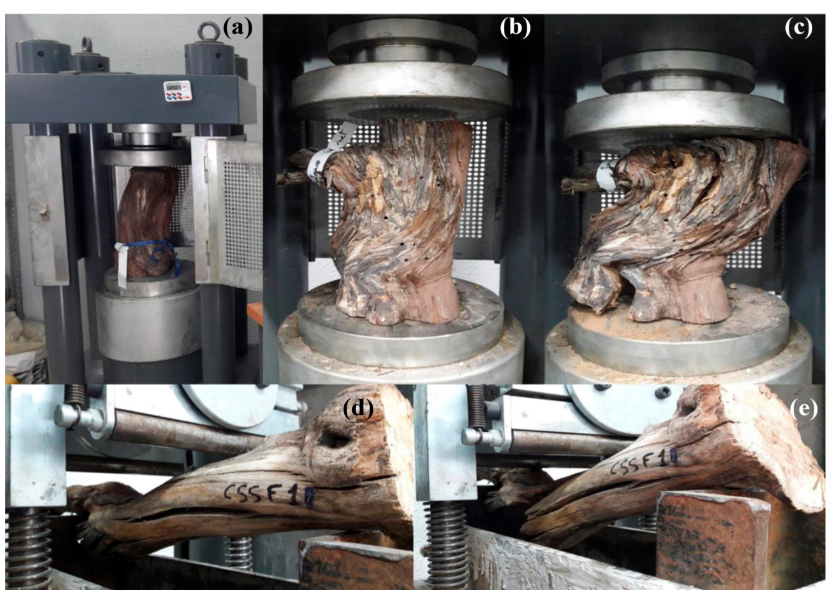

Figure 2: (a) Pictorial illustration of the hydraulic press used for compressive and flexural tests; (b) affected grapevine trunk before compressive test; (c) affected grapevine trunk after compressive test; (d) affected grapevine branch before flexural test; (e) affected grapevine branch after flexural test.

Test 3: TLCWS on wood branches and trunks

The cracks appearing on the surface of the grapevine wood samples after both compressive and flexural tests were measured from the fracture point. In order to make the cracks visible, talc powder was applied to the area and later on the excess of powder was shaken off. The cracks were then measured using a ruler and their lengths were added cumulatively to obtain the value of total length of the cracks in wood samples (TLCWS) (in mm) according to the methodology described by Persad *et al.* (2013).

Statistical analysis

In order to examine the effect of the cross sectional area (CSA) of grapevine wood samples (fixed factor) on compressive strength (CS) or flexural strength (FS) as a covariate an analysis of covariance (ANCOVA) was performed. The linear regression coefficients of the interaction CS (or FS) x CSA and FS x CSA were tested using an F-test. Data regarding the total length of the cracks of wood samples (TLCWS) were evaluated using analysis of variance (ANOVA) followed by a Fisher´s LSD test (significance at $p \leq 0,05$). Analyses were conducted using SPSS software, version 24 software (IBM SPSS Statistics, 1968, Armonk, NY, USA).

RESULTS AND DISCUSSION

Test 1: Mechanical strength of wood trunks (CS in relation to CSA)

Water content in fresh grapevine wood trunks of ´Tempranillo´ and ´Cabernet-Sauvignon´ varieties turned out to be 63,8 % and 57,0 %, respectively.

Up to a maximum of 6 exit holes/sample (Tempranillo) and 6 larvae galleries/sample (Cabernet-Sauvignon) were found in fresh damaged samples. Meanwhile, up to a maximum of 5 exit holes/sample (Tempranillo) and 2 larvae galleries/sample (Cabernet-Sauvignon) were found in dry damaged samples (Table 1).

Table 1: Number of external damages in grapevine wood trunk samples.

		Fresh trunks		Dry trunks	
External damage	Variety	Undamaged Wood	Damaged Wood	Undamaged Wood	Damaged Wood
Exit holes (n) (s/s/s)	Tempranillo	(3) (-/-/-)	(2) (6/3)	(7) (-/-/-/-/-/-/-)	(6) (2/2/4/2/3/5)
	Cabernet-Sauvignon	(4) (-/-/-/-)	(2) (4/7)	(3) (-/-/-)	(4) (2/2/3/4)
Galleries (n) (s/s/s)	Tempranillo	(3) (-/-/-)	(2) (3/1)	(7) (-/-/-/-/-/-/-)	(6) (1/0/1/2/1/1)
	Cabernet-Sauvignon	(4) (-/-/-/-)	(2) (5/6)	(3) (-/-/-)	(4) (1/1/0/1)

n = number of wood samples; s = number of samples with external damage; (-/-/-) = no data.

The CS supported by undamaged fresh grapevine trunks as function of the CSA was significantly high (F=6,387; d.f.=1,9; P=0,035) in comparison to damaged wood. The linear regression coefficients of the CSA x CS interaction were significantly different (F=18,372; d.f.=1,9; P=0,003) between damaged and undamaged trunks. The CS in trunks decreased with the increase in the CSA in both damaged and undamaged trunks, being the CS values lower in damaged wood (Figure 3a).

The CS supported by undamaged dry grapevine trunks as a function of the CSA was significantly high (F = 15,221; d.f.=1,22; P=0,001) in comparison to damaged wood. The linear regression coefficients of the CSA x CS interaction were significantly different (F=160,002; d.f.=1,22; $P \leq 0,001$) between undamaged and damaged trunks. The CS trunks decreased with the increase in the CSA (in damaged and undamaged trunks), being the CS values lower in damaged wood (Figure 3a).

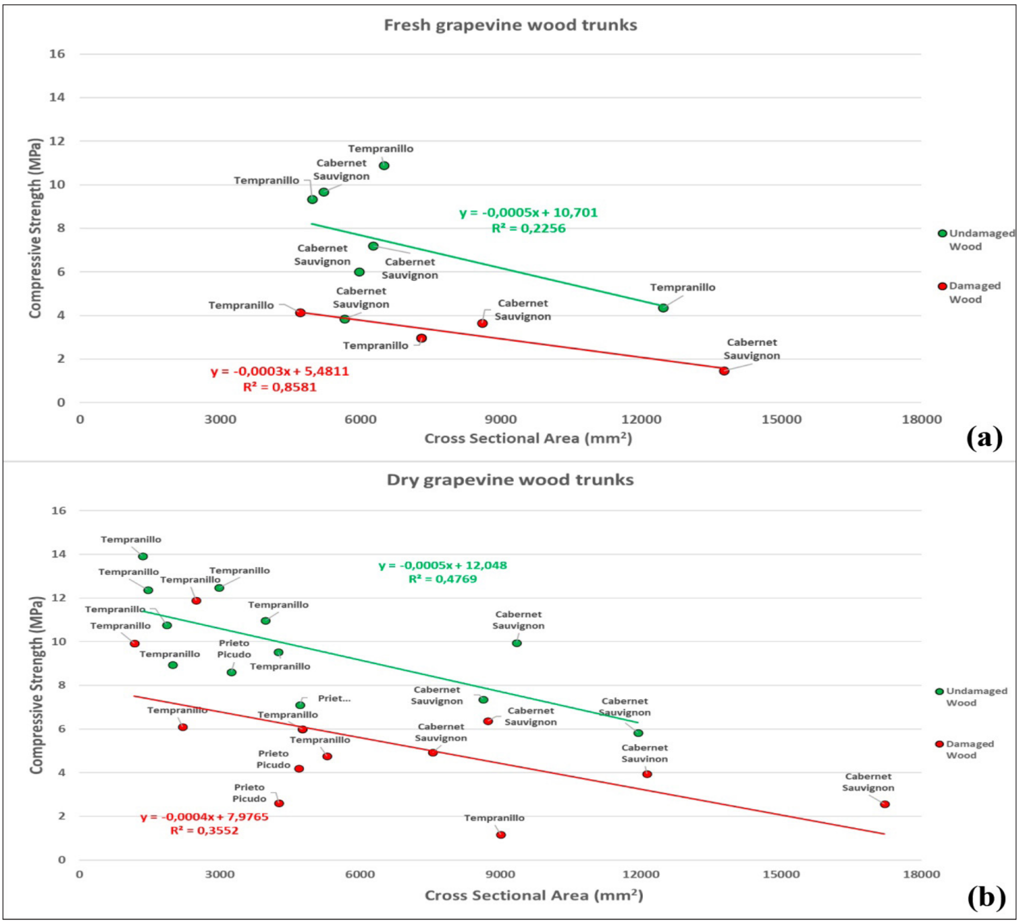

Figure 3: Linear regression of the compressive strength (CS) (MPa, y-axis) (a) fresh; (b) dry) in relation to cross sectional area (CSA) (mm^2, x-axis) in grapevine trunks. ´Green Points´ represent values for trunk samples of different varieties undamaged by *X. arvicola* larvae; ´Red Points´ represent values for trunk samples of different varieties damaged by *X. arvicola* larvae. ´Green Line´ is the trendline for ´Green Points´; ´Red Line´ is the trendline for ´Red Points´.

Mechanical strength of wood branches (FS in relation to CSA)

Water content in fresh grapevine wood branches of ´Tempranillo´ and ´Cabernet-Sauvignon´ varieties was 62,5 % and 59,6 %, respectively.

Up to a maximum of 3 exit holes/sample (Tempranillo) and 2 larvae galleries/sample (Tempranillo) were found in fresh damaged samples. Meanwhile, up to a maximum of 3 exit holes/sample (Tempranillo) and 3 larvae galleries/sample (Cabernet-Sauvignon) were found in dry damaged samples (Table 2).

Table 2: Number of external damages in grapevine wood branch samples.

External damage	Variety	Fresh branches Undamaged Wood	Fresh branches Damaged Wood	Dry branches Undamaged Wood	Dry branches Damaged Wood
Exit holes (n) (s/s/s)	Tempranillo	(4) (-/-/-/-)	(4) (1/1/3/2)	(7) (-/-/-/-/-/-/-)	(6) (1/3/1/1/2/1)
	Cabernet-Sauvignon	(8) (-/-/-/-/-/-/-/-)	(4) (1/1/2/1)	(2) (-/-)	(2) (2/1)
Galleries (n) (s/s/s)	Tempranillo	(4) (-/-/-/-)	(4) (1/1/3/1)	(7) (-/-/-/-/-/-/-)	(6) (0/3/2/2/1/1)
	Cabernet-Sauvignon	(8) (-/-/-/-/-/-/-/-)	(4) (1/1/1/2)	(2) (-/-)	(2) (1/2)

n = number of wood samples; s = number of samples with external damage; (-/-/-) = no data.

The FS supported by undamaged fresh grapevine branches as a function of the CSA was not significantly different between undamaged and damaged wood branches. The linear regression coefficients of the FS x CSA interaction were significantly different (F=34,21; d.f.=1,17; P≤0,001) between undamaged and damaged grapevine. The FS in branches decreased with the increase in the CSA in both trunks (undamaged and damaged). Moreover, the FS values were lower in damaged wood than in undamaged wood (Figure 4a).

The FS supported by undamaged dry branches as function of the CSA was significantly high (F=5,455; d.f.=1,20; P=0,031) in comparison to damaged wood. The linear regression coefficients of the FS x CSA interaction were not significantly different between undamaged and damaged branches. For undamaged wood, the FS of branches decreased with the increase in the CSA, while for the damaged branches, the FS increased with the increase in the CSA (Figure 4b). Grapevine wood branches are usually subjected to severe pruning during the entire growth, which causes a non-uniform growth of the wood fibers. This promotes the appearance of knots in the wood, which directly affect the strength and resistance of the wood.

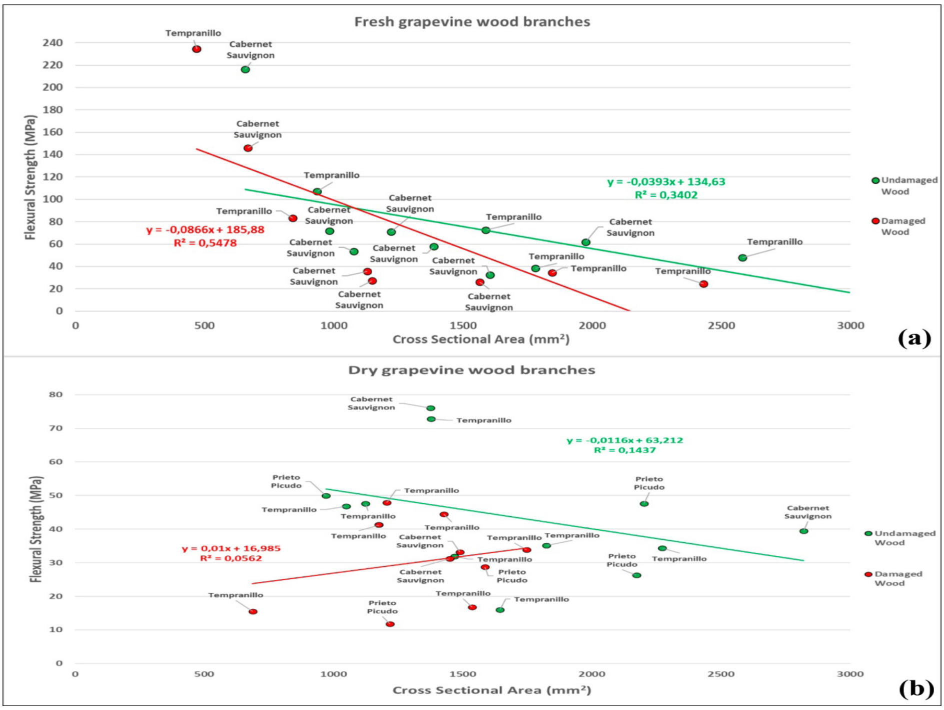

Figure 4: Linear regression of the flexural strength (FS) (MPa, y-axis) (A, fresh; B, dry) in relation to cross sectional area (CSA) (mm^2, x-axis) in grapevine branches. ´Green Points´ represent values for grapevine branch samples of different varieties undamaged by *X. arvicola* larvae; ´Red Points´ represent values for grapevine branch samples of different varieties damaged by *X. arvicola* larvae. ´Green Line´ is the trendline for ´Green Points´; ´Red Line´, is the trendline for ´Red Points´.

This study shows how *X. arvicola* larvae negatively affect the mechanical behaviour of *V. vinifera* wood. These damages caused a decrease in the resistance of grapevine wood greater as its CSA increased and a longest TLCWS (regardless of the wood is fresh or dry, or if it subjected to compressive or flexural test´s). This phenomenon in woody species, was also observed when *X. arvicola* larvae attack *Prunus pisardi* Carrière, Koehne (Rosales: Rosaceae) trees, resulting in the weakness of the affected trees and/or the death or breakage of the affected branches during several years (Biurrun *et al.* 2007).

CS and FS decreased with the increase in the CSA irrespective of the part of the plant (branches and trunks), damage condition (undamaged and damaged) and water content (fresh and dry), significantly more accentuated in damaged than in undamaged wood. It was also verified through the linear regression coefficients of the CS x CSA interaction that significant differences between undamaged and damaged grapevine wood samples showed up in fresh trunks, dry trunks and fresh branches. The grapevine wood is subjected to severe pruning during the entire growth period to build up a defined training system. However, this pruning causes a non-uniform growth of the wood fibers, promoting the appearance of knots and cracks in the wood, which will directly affect the strength and resistance of the wood. Therefore, this fact will explain the decrease in both CS and FS as the CSA rises in undamaged wood samples because older wood has been subjected to more pruning cuts throughout its life. Moreover, a greater CSA implies that a more significant volume in timber could be attacked by *X. arvicola* larvae. This agrees with the decrease in both CS and FS as the CSA increases in damaged branches and trunks (fresh and dry). This would explain the downward slope of the trendline for the linear regressions obtained for fresh and dry trunks, and fresh branches, all whose wood samples had CSA greater than 2000 mm^2, as Rodríguez-González *et al.* (2019) already observed in wood varieties. On the other hand, dry branches with a CSA lower than 2000 mm^2 in all the samples, did show a trendline with an upward slope for the linear regressions afore mentioned. Thus, wood samples with a smaller CSA had few galleries inside the wood, so the resistance of the wood was not severely damaged. Previous studies carried out by Rodríguez-González *et al.* (2020) only allowed us to conclude that the vine wood damaged by these larvae had a lower resistance and a higher breaking speed than undamaged wood.

X. arvicola larvae, like the larvae of other cerambycids, altered the mechanical behaviour of the trunk and branches of grapevine varieties. The effects of a continuous infestation of the grapevines by these larvae result in greater changes in the plants, for example, leaf development becomes scarce, the shoots are not very vigorous and productive the clusters are smaller, the flowers are less numerous, diminish their length, and they come off more quickly (Ocete *et al.* 2002b, Moreno *et al.* 2004). It has been stated that branches breakage due to physical properties can reduce plant fitness because of biomass and meristem loss, showing comparable results of biomechanic effects on *Tsuga canadensis* (Pinales: Pinaceae) produced by *Adelges tsugae* (Hemiptera: Adelgidae) (Soltis *et al.* 2014). Similar results were obtained by the effect of *Monochamus galloprovincialis* (Coleoptera: Cerambycidae) and *Acanthocinus aedilis* (Coleoptera: Cerambycidae) on *Pinus sylvestris* (Jankowiak and Rossa 2007). Adults of some cerambycid species select healthy trees for oviposition, whereas other choose unhealthy ones and, subsequent larval feeding and development can kill both kinds of trees (Allison *et al.* 2004).

Wood damages caused by *X. arvicola* larvae can be direct, caused by the reduction of vascular tissues of the plant which are ingested by larvae, resulting in a damaged grapevine with a lower resistance to bear crop loads, or indirect, because of the propagation of wood diseases in already affected wood that killed the vascular tissues of the wood. Thus, *X. arvicola* larvae damage grapevine wood and favor the propagation of grapevine trunk diseases through the emergency holes originated by *X. arvicola* insects on their way out of the wood, leading to the death of plant vascular tissue (Ocete *et al.* 2002a, García-Ruiz 2009). The fungal attack in ´Tempranillo´ and ´Cabernet-Sauvignon´, is more severe than in other varieties (Ocete *et al.* 2002a). The fungal symbionts of cerambycid beetles are endosymbiotic fungi, and they play an important role as suppliers of enzymes for degradation of organic matter, particularly wood (Buchner 1965, Dominik and Starzyk 1989, Jones *et al.* 1999). The fact that wood pathogens or diseases affect the biomechanical properties of woody species is already described in other genera, such as *Pseudotsuga* spp. (Hansen *et al*. 2000) and *Pinus* spp. (Jankowiak and Rossa 2007, Drenkhan *et al.* 2006). According to Hauer *et al.* (1993), species affected by wood diseases accumulate a higher amount of dead wood, which results in a fragility, leading to a progressive death in the affected areas. An accumulation of dead wood caused by the attack of pathogens on branches or trunks predisposes the affected species to damage or breakage when they are subjected to external agents, including snow, wind and/or static loads such as the weight of grapes the grapevine wood is exposed at the time of harvesting (Detters *et al.* 2008, James and Kane 2008).

Test 3: TLCWS on wood branches and trunks

Trunks under the CS, undamaged fresh showed the lowest TLCWS (30,71 mm), significantly lower than in damaged fresh (46,25 mm). In contrast, undamaged dry trunks also showed a significantly lower TLCWS (64,58 mm) than damaged dry trunks (86,66 mm). Dry wood trunks showed the greatest TLCWS (64,58 mm and 86,66 mm in undamaged and damaged, respectively), with values significantly greater than the respective ones in fresh trunks samples (30,71 mm and 46,25 mm in undamaged and damaged wood, respectively) (Table 1).

Branches under the FS, undamaged fresh branches showed the lowest TLCWS (58,08 mm), significantly lower than in damaged fresh branches (85,62 mm), whereas undamaged dry branches also showed a significantly lower TLCWS (77,91 mm) than damaged dry branches (166,50 mm). Dry wood branches showed the greatest TLCWS (77,91 mm and 166,50 mm in undamaged and damaged, respectively), with values significantly greater than the respective ones in fresh branches samples (58,08 mm and 85,62 mm in undamaged and damaged, respectively) (Table 3).

Damaged wood trunks (fresh and dry) evaluated on several *V. vinifera* varieties had a greater TLCWS than the undamaged trunks. A similar trend was observed in damaged branches (fresh and dry) compared to those undamaged. Moreover, the TLCWS, within the same damage condition (undamaged or damaged) and part of the plant (trunk or branch), was significantly higher in dry samples than in fresh samples. These branches and trunks turned out to be more vulnerable to mechanical stress where the grapevines are growing, as has been described for other woody species (Soltis *et al.* 2014). Rodríguez-González *et al.* (2019) showed that damaged wood of the ´Cabernet-Sauvignon´ variety could have their structural capacity reduced up to 62 % (compared to undamaged plants of the same variety) when subjected to the usual crop loads. In *V. vinifera*, the weight of the grapes, and the shaking produced by harvesting machines, could be two fundamental factors conditioning the wood resistance and therefore, the structural capacity of the grapevines damaged by *X. arvicola* larvae. TLCWS followed similar patterns, so relationships between fresh and dry wood samples (with a different water content) and different infestation levels could be established in future research.

Table 3: Total length of the cracks in wood samples (TLCWS) of different grapevine varieties under mechanical strength tests (compressive strength on trunks and flexural strength on branches).

Compressive Strength				Flexural Strength			
	Undamaged Wood (n;v)	Damaged Wood (n;v)			Undamaged Wood (n;v)	Damaged Wood (n;v)	
Fresh Trunks	30,71 ± 0,71bB (3;Tempranillo) (4;C.Sauvignon) (0;P.Picudo)	46,25 ± 8,50aB (2;Tempranillo) (2;C.Sauvignon) (0;P.Picudo)	F=6,211 d.f.=1,9 *P*=0,034	Fresh Branches	58,08 ± 6,31bB (4;Tempranillo) (8;C.Sauvignon) (0;P.Picudo)	85,62 ± 6,08aB (4;Tempranillo) (4;C.Sauvignon) (0;P.Picudo)	F=8,933 d.f.=1,18 *P*=0,008
Dry Trunks	64,58 ± 8,15bA (7;Tempranillo) (3;C.Sauvignon) (2;P.Picudo)	86,66 ± 7,16aA (6;Tempranillo) (4;C.Sauvignon) (2;P.Picudo)	F= 4,144 d.f.=1,22 *P*=0,050	Dry Branches	77,91 ± 5,68bA (7;Tempranillo) (2;C.Sauvignon) (3;P.Picudo)	166,50 ± 15,70aA (6;Tempranillo) (2;C.Sauvignon) (2;P.Picudo)	F=32,330 d.f.=1,20 *P*=<0,001
F =	9,803	8,990		F =	5,444	19,161	
df =	1,17	1,14		df =	1,22	1,16	
P =	0,006	0,010		*P* =	0,029	<0,001	

n = number of samples; v = grapevine variety; Different lowercase letters means significant differences between undamaged and damaged grapevine wood within the same water content of the wood (fresh or dry), part of the grapevine (trunk or branch) and mechanical strength (compressive or flexural) (p≤0,05).

Different capital letters means significant differences between fresh and dry wood within the same damage condition (undamaged or damaged by *X. arvicola* larvae), part of the grapevine (trunk or branch) and mechanical strength (compressive or flexural) (p≤0,05).

CONCLUSIONS

Grapevine wood damaged by *X. arvicola* suffered a reduction in mechanical strength (compressive and flexural). CS and FS in wood tested samples decreased with the increase in their CSA, irrespective of the part of the plant, condition or water content. The interaction CS (or FS) x CSA showed significant differences between undamaged and damaged grapevine wood samples. Damaged wood trunk and branches samples had a greater TLCWS than undamaged samples, whereas TLCWS was higher in dry samples than in fresh samples. These damages in the wood would result in a higher vulnerability to the mechanical stress suffered by the grapevines in the field (heavy winds, crop load and plant canopy weights), and would lead to a higher exposure to the mechanical stress applied by harvesting (vibration) or pruning (traction) machines. Larvae of this insect altered the mechanical behaviour of grapevine wood and the mechanical strength of the wood, which was negatively affected when the CSA increased. Longer TLCWS was found in damaged wood.

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