Effects of Cutting Patterns of Shears on Occlusion Processes in Pruning of High-Quality Wood Plantations

Enrico Marchi, Francesco Neri, Marco Fioravanti, Rodolfo Picchio, Giacomo Goli, Giuseppina Di Giulio

Abstract – Nacrtak

Arboriculture plantations aim to produce high-quality wood. In order to investigate the type and extent of mechanical injury that pruning causes to tree cambium as well as the effects on the healing process, different types of shear were selected and used in an eight-year-old Quercus robur *L. plantation. The amount of removed, detached and crushed bark was assessed by means of image analysis immediately after pruning. After 15 months, the effect of different cutting patterns on the healing process was investigated by measuring the area of the pruned branch covered by woundwood (HI_1). Five years after pruning, the same analysis was performed above and below bark (HI_{o5} and HI_{u5}) and a number of parameters were assessed in order to quantify the quantity and quality (symmetry) of woundwood growth and the healing time for sealing. The action of pruning tools depends on cutting pattern and branch diameter. The greater the diameter, the longer the healing time. The double-blade tool caused less injury and showed the fastest healing process. The use of double blade pruning tools is thus recommended to improve the performance of wood quality production in arboriculture plantations. We also recommend the healing index HI_1 for an early assessment of pruning damage.*

Keywords: pedunculate oak, pruning tools, agroforestry, wood quality, occlusion

1. Introduction – *Uvod*

Forest trees have been pruned for centuries in order to increase wood quality and to shape the tree (O'hara 2007). Pruning meets different objectives, such as: fuelwood production; aesthetic improvement; dead branch removal, reduction or prevention of the attack of pathogens. However, the most important purpose of tree pruning is usually to increase the quality of the log to be used in sawing, peeling or slicing operations (O'hara 2007, Kupka 2007), in particular in plantation to produce high quality wood (Springmann et al. 2011). The main aim is to get at least 2.5 m of stem length without knots or related defects in logs with a diameter larger than 30–40 cm (Mohni et al. 2008). In fact, on average, the butt log represents 90% of a tree's economic value (Kronauer 2009) and knot should be limited to the inner 8–10 cm of the log diameter. This suggests the need for early pruning.

After accurate pruning action, the wood growth will likely be free of defects and will consequently achieve greater wood quality than unpruned trees. Nevertheless, branch cutting is a stressful action for trees (Springmann et al. 2011) and pruning should avoid a sudden reduction of the total leaf area, so that the growth increment is kept regular. A severe pruning or pruning that removes foliage solely from the upper crown will improve stem form and reduce the size of the defected core thereby increasing clearwood production (Medhurst et al. 2006). However, it may also reduce tree growth or stimulate a tree response by developing secondary shoots (Alcorn et al. 2008), thus having a negative effect on clearwood production.

The effects of pruning on wood quality involve a lot of factors: e.g. pruning season, pruning methods, tree species, as well as the diameter of the cut branches, which in high quality arboriculture plantation should be lower than 3 cm (DeBell et al. 2006, Dujesiefken et al. 1998, 2005, Nicolescu and Kruch 2009).

Many studies on tree pruning concern the methods of branch removal and subsequent compartmentalization (Shigo and Marx 1977) and wound occlusion. These studies show contrasting results. Several works indicate that a cut close to the stem is effective for pruning trees for a more rapid occlusion and to enhance wood quality by avoiding infections of fungi or bacteria (Brodie and Harrington 2006, DeBell et al. 2006). Other studies indicate that for a proper pruning the branch collar should not be removed from the stem, thus improving compartmentalization response (Shigo 1984, Dujesiefken et al. 1998, Smith 2006).

A more rapid occlusion in trees with faster radial growth rates, both conifers and broadleaves, was observed (Roth 1948, O'Hara and Buckland 1996, Petruncio et al. 1997). Some studies revealed a more rapid occlusion after pruning live branches than dead branches and dead branches occluded more rapidly if the branch collar was intentionally injured during pruning (Brodie and Harrington 2006).

The mechanical injuries caused to the bark along the perimeter of the cutting section affect the healing process, they may favour abnormal wood coloration/discoloration and/or pathogen attacks, and, ultimately, they reduce timber quality and value (Pearce 2000, Dujesiefken et al. 2005, Brunetti et al. 2006, Nocetti et al. 2011).

Infection from fungal decay organisms has always been a concern with pruning. However, many authors found little or no evidence of decay in broadleaved trees in the northern hemisphere (Chiu et al. 2002, DeBell et al. 2006) and sometimes found less decay in pruned trees than unpruned trees (Skilling 1958). Nevertheless, pruning of thicker branches may cause extensive discolouration and decay in the trunk even though the cuts are made correctly (Dujesiefken et al. 1998).

In this considerable international body of literature on tree pruning, there is a dearth of studies on the effects of pruning tools. Very few studies performed until now consider the effect of pruning tool cutting pattern (Baldini et al. 1997, Marchi and Rossi 2007, Schatz et al. 2008). Other studies on different pruning tool cutting patterns were focused only on the force requirements for manual pruning (Crossland et al. 1997, Parish 1998). The use of different cutting patterns in fact could result in different occlusion time, wounding patterns, wood defects, defects extension into the bole, and decay.

The aim of this paper was to investigate the relation between pruning tools cutting patterns and the mechanical injury to tree bark in *Quercus robur* L. plantation, and to analyze the effect of the cutting pattern of pruning tools on occlusion processes. These results will help to minimize direct and indirect unfavorable pruning effects on wood quality, and to give a contribution in improving research on the methods of branch removal and subsequent wound occlusion.

2. Materials and Methods – *Materijal i metode*

A pruning operation was carried out in an eight-year-old plantation located in S. Barbara (Arezzo – Central Italy – 43°34′59.49″ N, 11°28′23.39″ E). It was a mixed stand of *Q. robur*, as the main species, and *Alnus cordata*, as a secondary species. The planting pattern was square with 3 meters between the trees and the main and the secondary species were alternate along the row and between the rows.

In the pruning campaign, carried out in April 2006, three shears with different cutting patterns were used (Fig. 1): bypass (BP), draw cut (DC) and double blade (DB). The shears were selected to represent the range of tool designs currently used in Italy. Thirteen trees of *Q. robur* (Table 1) were selected for a total of 36 branches cut by each shear. For every single tree the branches were cut with the same shear. For each branch cut the diameter, the height above ground and the angle with reference to the North were measured (the first with a caliper, the second with a measuring tape and the last one using a Minerva compass) in order to be able to locate the cuts subsequently.

In pruning, the cut left the branches bark ridge and the branch collar intact; only branches less than 3.5 cm in diameter were cut. To evaluate mechanical injury, each cutting section was photographed with a macro-objective. The camera was parallel to the cut surface. The amount of bark injury to the section perimeter was estimated by means of a CAD software (AutoCAD 2002, Autodesk Inc., USA). The bark injury (BI) was quantified by measuring the angle included in the arc of the injured section perimeter (Fig. 2).

Fifteen months later, the cutting sections were re-photographed with the same method and they were compared with the pictures taken after pruning. The area of each cutting section covered by callus and woundwood (HA) was determined by means of an image analysis software (ImageJ 1.39u, National Institute of Healh, USA), and then compared with the total area of each wound after pruning (TA). A healing process index (HI) was calculated as a ratio between HA and TA.

Table 1 Characteristics of the Quercus robur trees at the time of pruning (2006): DBH, diameter at breast height, and diameter and height above ground level of the pruned branches (*S.E.* and *N*). The values of felled trees refer to 2006. DBH was measured overbark on standing trees in 2006 and underbark on crosscut sections in 2011. The differences among groups were not statistically significant (Kruskal-Wallis test, *p*-level 0.05)

Tablica 1. *Značajke stabala hrasta lužnjaka u vrijeme orezivanja grana (2006): DBH, prsni promjer; promjer orezanih grana i visina grana od tla (standardna pogreška i* N*). Vrijednosti se odnose na 2006. godinu. Prsni je promjer mjeren s korom na dubećim stablima 2006. godine i bez kore na isječcima 2011. godine. Razlike među grupama nisu bile statistički značajne (Kruskal-Wallisov test, p-level 0.05)*

		Tree DBH, mm *Prsni promjer stabla,* mm	Branch diameter, mm *Promjer grane,* mm	Height a.g.l., cm *Visina od tla,* cm
All trees in 2006 *Sva stabla 2006.*	DB	50.0 (4.6 $N=5$)	15.7 (0.1 $N=36$)	152.9 (7.8 $N=36$)
	BP	60.2 (13.3 $N=4$)	15.7 (0.1 $N=36$)	142.9 (10.2 $N=36$)
	DC	61.4 (2.7 $N=4$)	17.0 (0.1 $N=36$)	147.9 (10.6 $N=36$)
Trees felled in 2011 *Stabla posječena 2011.*	DB	48.2 (8.1 $N=3$)	15.7 (0.1 $N=21$)	164.7 (12.4 $N=21$)
	BP	65.8 (16.7 $N=3$)	15.8 (0.1 $N=32$)	143.6 (11.3 $N=32$)
	DC	61.0 (2.7 $N=4$)	17.0 (0.1 $N=36$)	147.9 (10.6 $N=36$)

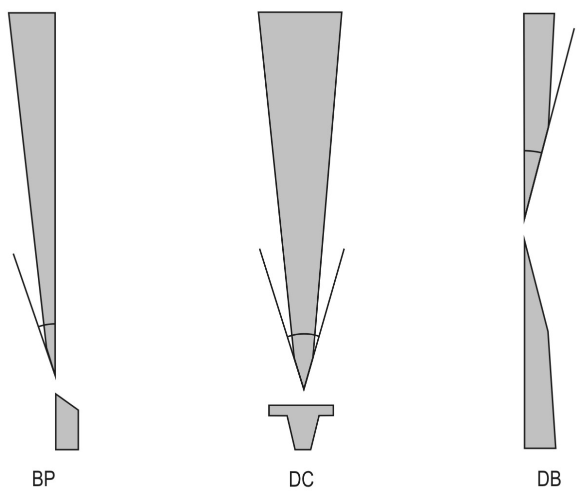

Fig. 1 Outline of cutting pattern
Slika 1. *Izgled načina rezanja*

Five years after the pruning campaign (March 2011), ten pruned trees were cut for a total of 21, 32 and 36 cutting sections for DB, BP and DC, respectively. The cutting sections were re-photographed and measured in order to compare them with the previous results and pictures (taken immediately after pruning

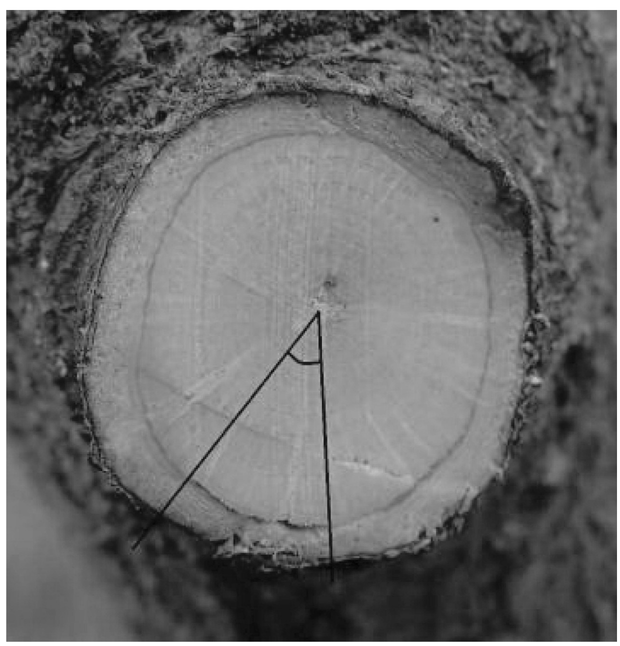

Fig. 2 Example of the method used for measuring the damage to cambium in fresh cuttings. The injury was quantified by measuring the angle included in the arc of the injured section perimeter
Slika 2. *Primjer metode korištene za mjerenje oštećenja kambija na svježim prerezima. Ozljeda je kvantificirana mjerenjem kuta kružnoga isječka na čijem se luku nalazi oštećenje*

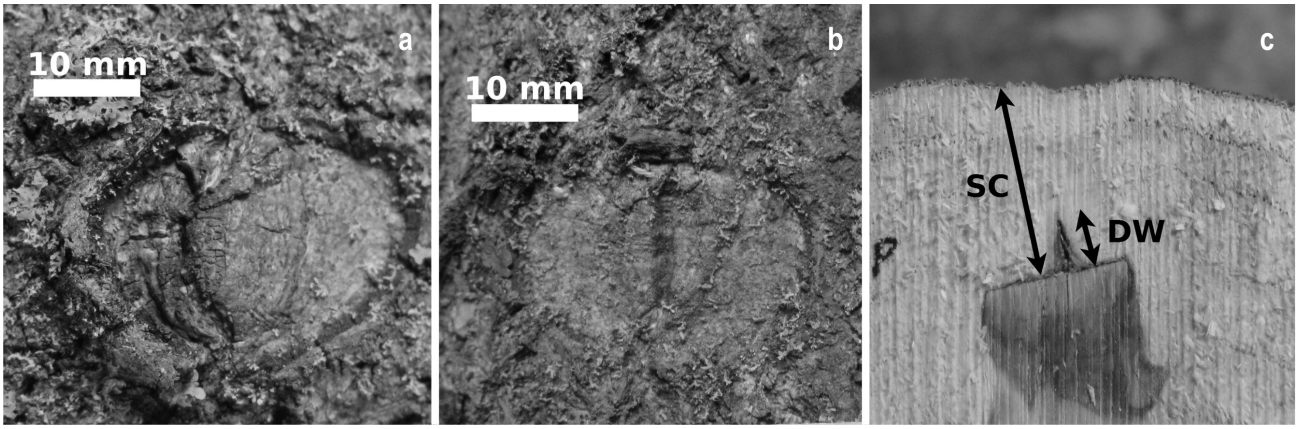

Fig. 3 Asymmetrically (a) and symmetrically (b) healed cuts, and cross section (c) with detail of: distance between cutting section and underbark stem perimeter (SC) and thickness of entrapped cork layer (DW)

Slika 3. *Asimetrično (a) i simetrično (b) zarasli rezovi te presjek (c) s detaljima: udaljenost mjesta reza od plašta debla bez kore (SC) i debljina urasle kore (DW)*

and fifteen months after pruning) by measuring overbark HI (HI_{o5}). Moreover the cutting sections that had not completely healed were counted and measured. The symmetry of the healing process for each cutting tool was measured and a symmetry index (HSI) was calculated as a ratio of the lower and higher value of the distance between the perimeter of the cutting section and the contact line of callus (an asymmetrically healed cut is shown in Fig. 3a and a symmetrical healed cut is shown in Fig. 3b). Some pruned brunches (4 for DB, 4 for BP and 9 for DC) were no longer visible overbark; for these branches the HSI was not calculated. The distances were measured by a ruler to the nearest 0.5 mm. Then, the bark over the cutting sections was carefully removed in order to measure the area of each cutting section covered by woundwood (HA_u).The healing process index underbark (HI_{u5}) was then calculated as a ratio between (HA_u) and the total area of each woody section after pruning.

Finally, each stem was crosscut at the knot level and the knots were analyzed. Two, two and four knots obtained by DB, BP and DC, respectively, were no longer recognized. On each cross section the following variables were measured (Fig. 3c): distance between the cutting section of the branch when pruned and underbark stem perimeter (SC); thickness of entrapped cork layer (DW); number of years to complete the healing process (HT). In relation to the unhealed knots, in order to not exclude these cases from the analysis, we considered that the unsealed branch would seal in 1 more year, i.e. a value of 6 years was adopted. A damaged woundwood index (DWI) was calculated as a ratio between DW and SC.

The value of underbark DBH in 2006 and 2011 was measured for each felled tree on the cross section at 1.3 m above ground. The values of SC, DW and DBH were measured by a ruler to the nearest 0.5 mm.

Data were checked for normality (Kolmogorov-Smirnov test) and homogeneity of variance (Levene test). The Kruskal-Wallis non-parametric multiple-comparison test was used to test differences between non normally distributed variables (Sprent and Smeeton 2001, Lo Monaco et al. 2011, Picchio et al. 2009), e.g. tree diameter, branch height above ground, HI_1, HI_{u5}, HSI, SC, DWI, and HT. In order to test the differences between the characteristics of trees and branches at the time of pruning (2006), the same test, i.e. Kruskal-Wallis, was also applied to cut branch diameter. A one-way ANOVA was applied to determine the effects of cutting pattern on the extent of injury immediately after pruning (2006), and differences were tested by the Tukey *HSD* test. All differences were considered as significant when $p \leq 0.05$. A multiple linear regression was applied to test the relation between type of pruning tools, years for the healing process to be complete and branch diameter. All statistics used the Statistica 7.0 software (StatSoft, Tulsa OK, USA).

3. Results – *Rezultati*

Non-significant statistical differences were found in the diameter at breast height (DBH), in the diameter of the cut branches and in the height above ground level of the branches of the thirteen trees in 2006 and of the ten felled trees in 2011 (Table 1).

3.1 Mechanical injury immediately after pruning *Mehanička ozljeda neposredno nakon orezivanja*

Three kinds of bark injury were found over the cutting section perimeter, namely: crushing, i.e. the bark appeared to be more compact; detaching, i.e. the bark was separate from the wood; and removal, where some bark parts were missing. The cutting pattern did not significantly affect the kind of injury (data not shown), while the extent of injury varied in the following order: DB < DC < BP ($p < 0.001$) (Fig. 4).

3.2 Healing process after 15 months – *Proces zaraščivanja nakon 15 mjeseci*

The cutting pattern significantly affected HI_1 ($p <$ 0.001). Cuts made using double blade tools showed a quicker healing process, while draw cut and bypass showed a slower and similar healing process (Fig. 5).

72% of the branches cut by DB completely healed their wounds (HI_1), and 19% closed 90% of the wound. In contrast, just 11% and 8% of branches cut by BP and DC respectively attained complete healing (Fig. 6a).

Callus and woundwood developed in a quite circular pattern in the healing process of cuts made by double blade tools, whereas when using bypass and draw cut tools they developed an irregular shape (Fig. 7). In particular, 50% of the branches cut by draw cut shears developed callus and woundwood mainly on one side, i.e. the side cut by the blade (data not shown).

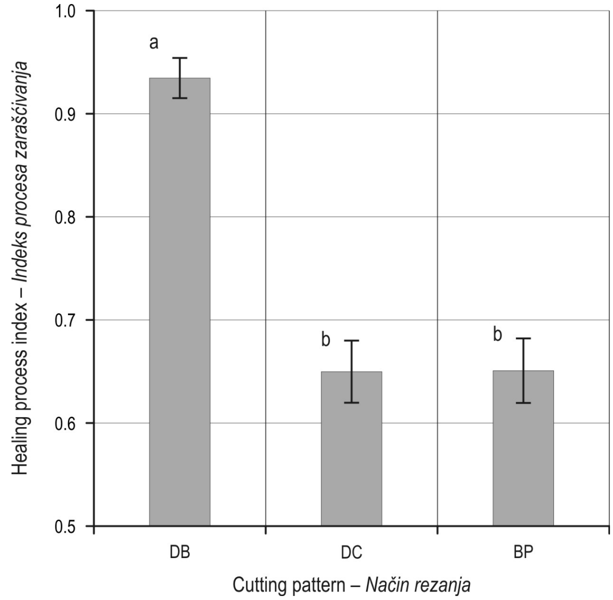

Fig. 5 Healing process index (HI_1) fifteenth month after pruning (2007) for different cutting patterns (+/– *S.E.*). Different letters show significant differences (Kruskal-Wallis multi-comparison test, $p < 0.05$, $N = 36$)

Slika 5. *Indeks procesa zaraščivanja (HI1) petnaest mjeseci nakon orezivanja (2007) za različite načine rezanja (+/– standardna pogreška). Različita slova pokazuju signifikantne razlike (Kruskal-Wallisov multiusporedni test,* p < *0.05,* N = *36)*

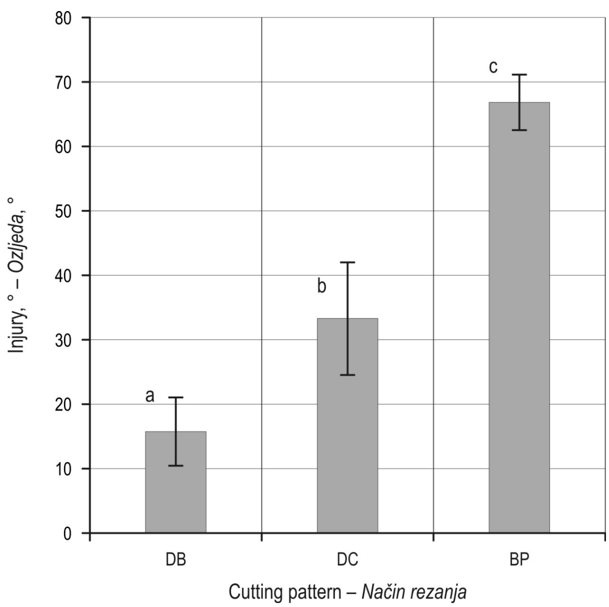

Fig. 4 Damage assessed immediately after pruning (2006) for different cutting patterns (+/– *S.E.*). Different letters show significant differences (Tukey *HSD* test, $p<0.05$, $N = 36$)

Slika 4. *Oštećenje ustanovljeno neposredno nakon orezivanja (2006) za različite načine rezanja (+/- standardna pogreška). Različita slova pokazuju signifikantne razlike (Tukey* HSD *test,* p < *0.05,* N = *36)*

3.3 Healing process 5 years later – *Proces zaraščivanja nakon pet godina*

In 2011, cuts by DB confirmed their better ability to seal in shorter time periods. 100% of DB branches were completely healed, contrasting with only 90.6% of BP branches and 71.9% of DC branches (Fig. 6c). However, no statistically significant differences arise for HI_{u5} (Table 2). A large part of the wounds were sealed, and HI_{o5} was almost 1 (Fig. 6b).

DB showed a more symmetrical healing process, followed by BP, but not significant differences ($p = 0.09$) were observed (Table 2). A symmetrical healing process could mean that the cambium worked well on both sides and this could lead to shorter sealing times.

The distance between the cutting section of the branch and the underbarked stem perimeter (SC) was higher in the knots obtained by DB and BP than in DC knots (Table 2), i.e. BP and DB resulted in shorter sealing times.

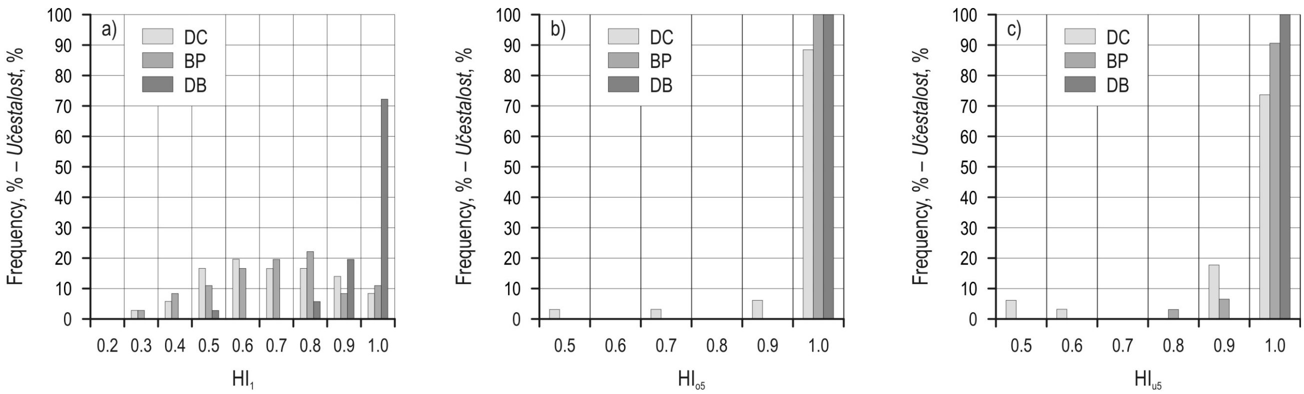

Fig. 6 Distribution of healing process index (HI) classes (%) – 3 shears: double blade (DB), bypass (BP) and draw cut (DC) – *Quercus robur* L. – a) HI_1: healing index assessed fifteen months after pruning; b) HI_{o5}: healing index assessed overbark five years after pruning; c) HI_{u5}: healing index assessed underbark five years after pruning

Slika 6. *Distribucija po razredima indeksa procesa zaraščivanja (HI) – 3 tipa škara: s dvostrukim sječivom (DB), s mimoilaznim sječivom (BP) i s jednostrukim sječivom (DC) – Quercus robur L. – a) HI_1: indeks zaraščivanja ustanovljen petnaest mjeseci nakon orezivanja; b) HI_{o5}: indeks zaraščivanja ustanovljen na kori pet godina nakon orezivanja; c) HI_{u5}: indeks zaraščivanja ustanovljen nakon uklanjanja kore pet godina nakon orezivanja*

DWI differed significantly between DB and DC (Table 2). DWI of DB and DC showed that 29% and 54% of the new wood, respectively, was damaged by entrapped cork layer. DB showed the shortest time for sealing the pruned branch (HT) while DC and BP did not differ. The healing time (HT) increased with increasing branch diameter for the three cutting patterns (Figure 8).

Finally a linear regression with dummy variable was performed to test the relation between years to complete the healing process, type of pruning tool and branch diameter (at 2006). The regression was statistically significant ($p < 0.001$; R^2adjusted = 0.27; SE = 1.13; MAE = 0.85) and the result is shown in Equation (1) and Fig. 8:

$$y = 3.96 - (0.76 \times t) + (0.05 \times D) \qquad (1)$$

Where y is the number of years needed for sealing, t the pruning tool pattern (dummy variable; DC=1, BP=2, DB=3), and D the branch diameter at cutting

Table 2 HI_{u5}, healing index assessed under bark; HSI, healing symmetry index; SC, distance between cutting section of a branch when pruned and underbarked stem perimeter; DWI, damaged woundwood index; HT, healing time five years after pruning by double blade (DB), bypass (BP) and draw cut (DC) shears (*S.E.* and *N*). Different letters show significant differences among values in a column (Kruskal-Wallis test, $p < 0.05$)

Tablica 2. *HI_{u5}, indeks zaraščivanja ustanovljen nakon uklanjanja kore; HSI, indeks simetrije zaraščivanja; SC, udaljenost između mjesta reza grane pri orezivanju i plašta debla bez kore; DWI, indeks oštećenja drva rane; HT, vrijeme zaraščivanja pet godina nakon orezivanja škarama s dvostrukim sječivom (DB), s mimoilaznim sječivom (BP) i s jednostrukim sječivom (DC) (*S.E. *i* N*). Različita slova označuju signifikantne razlike među vrijednostima u stupcu (Kruskal-Wallisov test,* p *< 0.05)*

Tool – *Oruđe*	HI_{u5}	HSI	SC, cm	DWI	HT, years – HT, *godine*
DB	1.00 (na $N = 21$)	0.81 (0.04 $N = 17$)	18.0 ^{a} (1.4 $N = 19$)	0.29 ^{a} (0.04 $N = 19$)	2.4 ^{a} (0.1 $N = 19$)
BP	0.99 (0.01 $N = 32$)	0.78 (0.04 $N = 28$)	18.4 ^{a} (1.1 $N = 30$)	0.42 ^{ab} (0.05 $N = 30$)	3.6 ^{b} (0.2 $N = 30$)
DC	0.95 (0.02 $N = 36$)	0.65 (0.05 $N = 27$)	12.1 ^{b} (0.6 $N = 32$)	0.54 ^{b} (0.06 $N = 32$)	4.0 ^{b} (0.2 $N = 32$)
p	ns	ns	< 0.001	< 0.03	< 0.001

na: not available because all the wounds were completely healed, i.e. HI_{u5} = 1 – *na: nije dostupno zbog toga što su sve rane potpuno zarasle, odnosno HI_{u5} = 1*
ns: not significant – *ns: nije signifikantno*

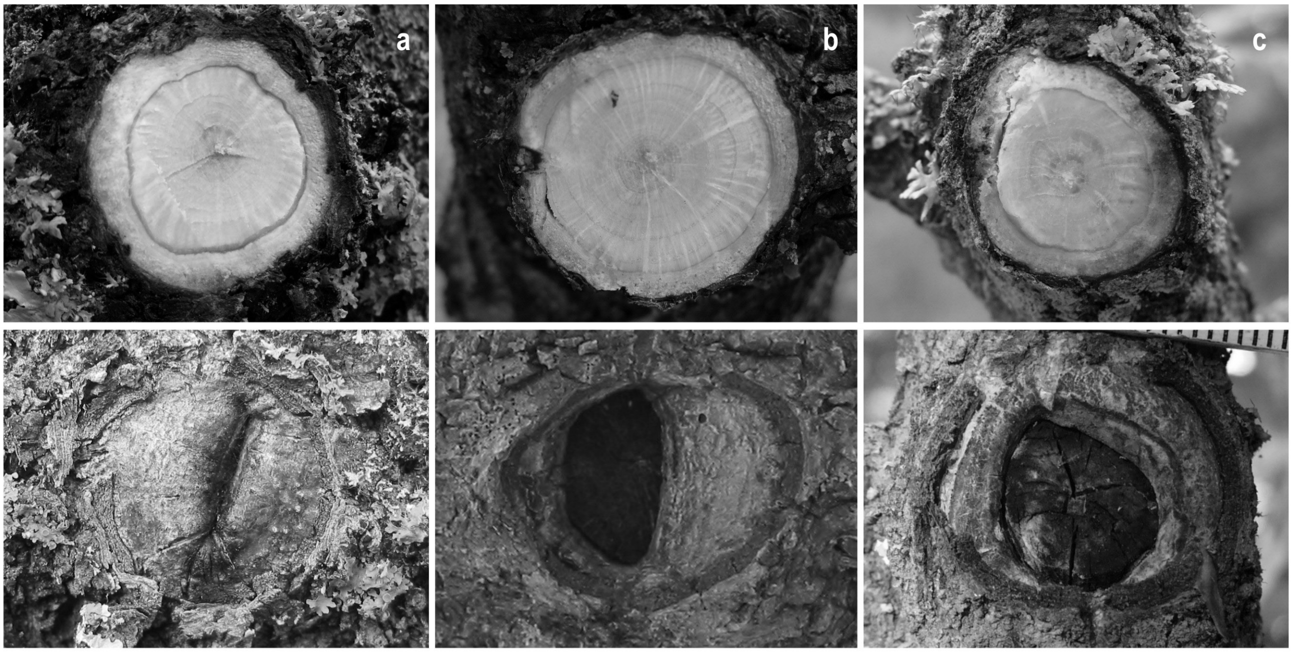

Fig. 7 Examples of a cutting section after pruning (above) and 15 months later (below). a – Double blade shear; b – Draw cut shear; c – Bypass shear. *Quercus robur* L.

Slika 7. *Primjeri mjesta reza nakon orezivanja (gore) i 15 mjeseci poslije (dolje.); a – dvostruko sječivo; b – jednostruko sječivo; c – mimoilazno sječivo.* Quercus robur *L.*

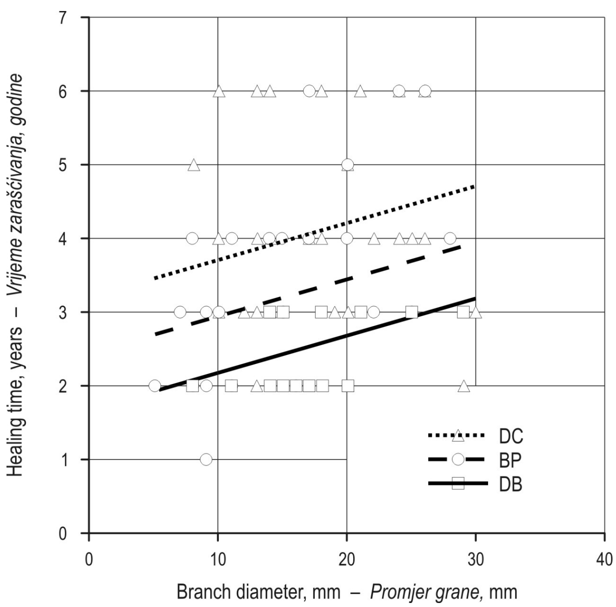

Fig. 8 Healing Time (HT in years) versus branch diameter per each cutting pattern

Slika 8. *Ovisnost vremena zaraščivanja (HT u godinama) o promjeru grane za pojedini način rezanja*

time. Only 27% of the variability of the healing time was explained by the independent variables considered.

4. Discussion and conclusion – *Rasprava i zaključak*

The analysis of damage caused by the different tools over time showed contrasting results. The injuries measured immediately after pruning showed that BP was the worst cutting pattern. Fifteen months later, no significant differences between DC and BP were recorded, suggesting that the injury caused by DC was underestimated when recorded immediately after pruning. Therefore, damage estimation by measuring the angle included in the arc of the injured section perimeter cannot be recommended for *Q. robur* immediately after pruning. This may be due to the higher patch area of the DC anvil relative to the BP hook which, together with the elevated *Q. robur* bark thickness, may have minimized the evidence of cambium compression during macroscopic analysis. In the long term (5 years), such a compression resulted in a decline of radial growth so that the distance between the cutting section and the underbark stem perimeter (SC) was lower for DC than for the other two tools. It may be interesting to apply the same method of pruning damage analysis to trees with a thinner and softer bark.

The healing index HI_1 applied one year after the pruning turned out to be a better parameter for early damage assessment. HI_1 is in fact a non destructive method, whose results were confirmed by the assessment of the healing time HT. HT was destructively applied five years after the pruning when most of the cuttings were sealed, which resulted in non significant differences in HI_5.

The woundwood analysis showed a minimum DWI value of 0.29 for the DB tool and a maximum value of 0.54 for DC. This means that the portion of stem core with knots or wood with defects will increase by 0.58 cm for DB and 1.08 cm for DC relative to the tree diameter at pruning time. Double-blade shears are, therefore, to be recommended for increasing the quality of timber. The time necessary to complete the healing process (HT) was less when DB was used, suggesting that double-blade shears maximize the quantity of high-quality timber. HT for BP and DC were 1.5 and 1.7 times higher than for DB, respectively. These figures may even be underestimated because the unhealed knots were given a further one-year period to complete the healing process. The hypothesis that a symmetrical healing process implied an optimal woundwood growth on both sides and thus shorter sealing times was not confirmed. In fact, the healing symmetry index (HSI) did not significantly depend on the pruning tool. The hypothesis that the larger the pruned branch diameter, the longer the time to seal (Joyce et al. 1998, Nicolescu and Kruch 2009) was confirmed, thus suggesting that early pruning (diameter < 3 cm) should be carried out.

The double-blade cutting pattern caused the least mechanical injury. We postulate that this is because both blades penetrate the wood and cut the bark tissues clean off. By contrast, the hook and the anvil of the other cutting patterns oppose the cutting force necessary for the blade to cut the tissue, but cause evident injury at the point of contact between the hook or the anvil and the bark. In DC the anvil patch area involves both the cut branch and branch collar causing bark injury close to the stem. In BP the hook patch area should involve only the cut branch but the lack of contact between the hook and the blade in the terminal phase of a cut causes injury. When the cutting parts of a by-pass tool come in touch with each other, and the branch starts bending downwards, the hook tends to slip, thus damaging the bark close to the stem.

Ultimately the DB tool showed the best pruning performance and is to be recommended as short healing processes may avoid pathogen attacks which cause a reduction of timber quality and value.

In conclusion, the effect of pruning tool used in branch removal on wound occlusion process is not negligible, suggesting that a higher attention to the pruning tool is recommended for improving research on the pruning methods and on the subsequent physiological response of trees.

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Sažetak

Utjecaji načina rezanja škara na zaraščivanje pri orezivanju stabala u plantažama za proizvodnju drva visoke kakvoće

Stabla se u plantažama orezuju radi proizvodnje visokokvalitetnoga drva. Da bi se odredili tip i opseg mehaničkih ozljeda koje orezivanje uzrokuje kambiju stabla te utjecaj na zaraščivanje, odabrani su različiti tipovi škara (s dvostrukim sječivom – DB, s jednostrukim sječivom – DC i s mimoilaznim sječivom BP) kojima je orezana osmogodišnja plantaža hrasta lužnjaka. Količina uklonjene, odvojene i nagnječene kore ustanovljena je analizom snimaka neposredno nakon orezivanja. Petnaest mjeseci nakon orezivanja mjerenjem zarasle površine orezane grane istraživan je utjecaj različitih načina rezanja na zaraščivanje. Na temelju zarasle i ukupne površine prereza određen je indeks procesa zaraščivanja (HI_1). Pet godina nakon orezivanja jednaka je analiza provedena mjerenjem na kori (HI_{o5}) i nakon uklanjanja kore (HI_{u5}). Osim toga ustanovljeni su i ostali parametri radi određivanja količine i kakvoće (simetrije) zaraščivanja te vremena zaraščivanja. Utvrđeno je da utjecaj oruđa za orezivanje ovisi o načinu rezanja i promjeru grane. S povećanjem promjera grane raste i vrijeme zaraščivanja. Uporaba oruđa s dvostrukim sječivom uzrokovala *je manje ozljede i brži process zarašćivanja. Stoga se radi poboljšanja kakvoće drva pri orezivanju plantaža preporučuje uporaba oruđa s dvostukim sječivom. Također se preporučuje primjena indeksa procesa zarašćivanja (HI_1) za rano određivanje štete uzrokovane orezivanjem.*

Ključne riječi: hrast lužnjak, oruđa za orezivanje, agrošumarstvo, kakvoća drva, zarašćivanje

Authors' address – *Adresa autorâ*:

Assoc. Prof. Enrico Marchi, PhD.
e-mail: enrico.marchi@unifi.it
Francesco Neri, PhD.
e-mail: francesco.neri@unifi.it
Marco Fioravanti, PhD.
e-mail: marco.fioravanti@unifi.it
Giacomo Goli, PhD.*
e-mail: giacomo.goli@unifi.it
Giuseppina Di Giulio
University of Firenze,
Department of Agricultural, Food and Forestry Systems (GESAAF)
Via S. Bonaventura 13
50145 Firenze
ITALY

Rodolfo Picchio, PhD.
e-mail: r.picchio@unitus.it
University of Tuscia,
Department of Agriculture, Forests, Nature and Energy (DAFNE)
Via S. Camillo de Lellis
01100 Viterbo
ITALY

*Corresponding author – *Glavni autor*

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