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Inovativna raba lesa, les kot vir zelenih kemikalij

Les pogosto opisujemo kot sekundarni ksilem, ki ga kambij v procesu sekundarne rasti debla ali veje proizvaja navznoter, v smeri stržena. Les lahko definiramo tudi kot trdo vlakneno snov, ki se nahaja pod skorjo debel in vej dreves in grmov. S kemijskega vidika pa les vidimo na nekoliko drugačen način, torej kot biokemijski proizvod dreves, hierarhično urejen naravni kompozit, ki je sestavljen iz treh osnovnih strukturnih gradnikov, iz celuloze, lignina in hemiceluloz, ter iz nestrukturnih komponent, spojin, z nižjo molekulsko maso.

Tako strukturne kot nestrukturne komponente lesa in skorje danes izkazujejo velik aplikativni potencial v različnih bioosnovanih produktih in so zato deležne velike znanstvenoraziskovalne pozornosti. Strukturne komponente lesa, predvsem nanoceluloza (CNF in CNC), lignonanoceluloza (LCNF) in lignin z ligninskimi nanodelci (LNPs), zaradi ugodnih fizikalnih in mehanskih lastnosti izkazujejo velik potencial na področju naprednih bioosnovanih materialov. Nestrukturne komponente lesa (NSCs), ki jih splošno poimenujemo ekstraktivi, se zaradi antioksidativnih in antimikrobnih lastnosti že uporabljajo kot naravni antioksidanti v prehranskih dopolnilih. Les in skorjo dreves torej obravnavamo kot obnovljiv vir zelenih kemikalij in dragocenih spojin, ki s svojimi lastnostmi ponujajo alternativo sintetičnim in okolju škodljivim kemikalijam in materialom.

Danes veliko beremo o trajnostni rabi in krožnem gospodarstvu. Sklop političnih pobud Evropske komisije, t.i. evropski zeleni dogovor, katerega glavni cilj je, da Evropska unija do leta 2050 postane podnebno nevtralna, vključuje tudi koncepte zelenega prehoda in krožnega gospodarstva, ki dajejo prednost recikliranju in trajnostni uporabi surovin, zlasti tistih naravnega izvora. V tem kontekstu kot strateško pomembno surovino obravnavamo tudi manj vredno drevesno biomaso, različne ostanke, ki se jih še vedno najpogosteje uporablja kot surovino v proizvodnji lesnih plošč ali kot vir energije. V Sloveniji že obstajajo lesni obrati z razvitimi stranskimi proizvodnimi tokovi, to so stranske vrednostne verige, ki dejansko producirajo izredno visoko dodano vrednost glede na vhodno surovino. V tej zgodbi je potrebno omeniti tudi pomembno vlogo Strateško razvojnih-inovacijskih partnerstev (SRIP, Mreže za prehod v krožno gospodarstvo), to so mreže partnerstev, ki omogočajo učinkovit prehod v krožno gospodarstvo. SRIP uspešno povezuje gospodarske subjekte, izobraževalno-raziskovalne in razvojne institucije ter različne nevladne organizacije v nove verige vrednosti po načelih ekonomije zaključenih snovnih tokov. Ta strateška partnerstva omogočajo učinkovit prenos znanja v prakso, s tem pa skušajo trajnostno povečati učinkovitost in konkurenčnost domačega gospodarstva. SRIP vsako leto organizira tudi študentske natečaje na področju bio-osnovanih inovacij (BISC-E), s čimer skuša študentom pomagati pri preboju na trg s krepitvijo njihovih kompetenc.

V pričujoči številki revije Les/Wood so predstavljeni izsledki analize verig vrednosti na področju konstrukcij in lesene gradnje v Franciji in inovativni pristop za obdelavo površine lesa z mešanico komercialno dostopnih olj in utekočinjenega lesa. Bralke in bralci boste dobili vpogled v mehanske in kemijske lastnosti lesa nekaterih manj znanih drevesnih vrst s plantaž v Gani. Predstavljen je tudi potencial ostankov mlete kave za proizvodnjo peletov in vpliv nanosa voska na barvo ter sijaj in indeks beline lesa ameriške čremse *(Prunus serotina)*. Želimo vam prijetno branje.

Innovative uses of wood, and wood as a source of green chemicals

Wood is often referred to as secondary xylem, which is formed by the cambium in the process of centripetal secondary stem growth. It can also be defined as a hard-fibrous substance under the bark of stems and branches of trees and shrubs. From a chemical point of view, we see wood somewhat differently, i.e. as a biochemical product of trees, a hierarchically ordered natural composite consisting of three basic structural components, cellulose, lignin and hemicelluloses, and non-structural components, i.e. compounds of lower molecular weight.

Both the structural and non-structural components of wood and bark have great application potential for various bio-based products and are therefore receiving considerable attention in research. The structural components of wood, especially nanocellulose (CNF and CNC), lignonanocellulose (LCNF) and lignin with lignin nanoparticles (LNPs), show great potential in the field of advanced bio-based materials due to their favourable physical and mechanical properties. The non-structural components of wood (NSCs), commonly referred to as extractives, are known for their antioxidant, antimicrobial and antimicrobial properties and are already used, for example, as natural antioxidants in dietary supplements. Wood and tree bark are therefore considered a renewable source of green chemicals and valuable compounds that provide an alternative to synthetic and environmentally harmful chemicals and materials.

Today, we read a lot about sustainability and the circular economy. A set of European Commission policy initiatives, such as the European Green Deal, whose main objective is to make the European Union climate neutral by 2050, also include the concepts of the green transition and circular economy, which prioritize the recycling and sustainable use of raw materials, especially those of natural origin. In this context, we also consider the less valuable tree biomass, various residues that are still most commonly used as a raw material for the production of wood panels or as a source of energy, as a strategically important raw material. In Slovenia, there are already timber plants with developed side streams, i.e. secondary value chains that generate high added value in relation to the raw material used. In this story, the extremely important role of the strategic research and innovation partnership (SRIP, Networks for the transition into circular economy), i.e. networks of partnerships that enable an efficient transition to a circular economy, must also be mentioned. The SRIP successfully connects companies, educational, research and development institutions and various non-governmental organizations in new value chains based on the principles of the circular economy. These strategic partnerships enable an efficient transfer of knowledge to industry in order to sustainably increase the efficiency and competitiveness of the domestic economy. Every year, the SRIP also organizes student competitions in the field of bio-based innovations (BISC-E), which aim to facilitate students' entry into the professional world by strengthening their competences.

This issue of the Les/Wood journal presents the results of the analysis of value chains in timber construction in France and the innovative approach of the staining of oil coatings with liquefied wood. Readers are also given insights into the mechanical and chemical properties of wood from selected tree species from plantations in Ghana, the potential of ground coffee residues for the production of pellets and finally the effects of applying wax on the colour, glossiness, and whiteness index values of American black cherry *(Prunus serotina)* wood. We wish you an enjoyable read.

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CELOSTNA ANALIZA VREDNOSTNE VERIGE LESENE GRADNJE V FRANCIJI

HOLISTIC ANALYSIS OF THE WOOD CONSTRUCTION VALUE CHAIN IN FRANCE

Peter Romih[1*], Jože Kropivšek[2]

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Izvleček / Abstract

Izvleček: Panoga lesene gradnje pripomore k zmanjševanju emisij in skladiščenju CO_2 ter vzpostavitvi krožnega gospodarstva. Za doseganje teh ciljev je potrebna visoka osredotočenost na regionalne vrednostne verige in vzpostavitev inovativnega ekosistema, ki lahko ustvari potrebne inovativne rešitve. V okviru evropskega projekta Basajaun je bila izvedena celostna analiza vrednostne verige lesene gradnje v francoski regiji Novi Akvitaniji, vključno z možnostmi ponovne uporabe in recikliranja. Analizirane so bile tudi strateške konkurenčne prednosti v verigi, ovire za vstop na trg, ovire pri poslovanju, sodelovanje med akterji, vpliv regulacij ter koordinacijske vloge v verigi, s poudarkom na prepoznavanju ovir in priložnosti za integracijo procesov odprtega inoviranja. Podatki so bili zbrani s pregledom sekundarnih virov in s kvalitativno metodo globinskih intervjujev. Več kot polovica intervjuvancev je prepoznala odprto inoviranje kot močno konkurenčno prednost, ob čemer so navedli tudi številne ovire, ki zavirajo procese odprtega inoviranja. Identificirali smo številne priložnosti za nadgradnjo verige lesene gradnje na področjih digitalizacije, upravljanja virov, krožnega gospodarstva, krepitve raziskovalnih in razvojnih aktivnosti ter povezovanja akterjev v verigi. Priložnosti za nadaljnji razvoj vrednostih verig na področju lesene gradnje je veliko, kar na eni strani narekuje potrebo po usklajenih regionalnih politikah na tem področju in hkrati iskanje rešitev na nacionalni (in evropski) ravni.

Ključne besede: vrednostna veriga, lesena gradnja, odprto inoviranje, krožno gospodarstvo, digitalizacija

Abstract: The wood construction industry contributes to building a circular economy, reducing emissions and storing CO_2. Achieving these goals requires a strong focus on regional value chains and building an innovative ecosystem that can produce the innovative solutions needed. As part of the European Basajaun project, a comprehensive analysis of the wood construction value chain in the New Aquitaine region of France was conducted, including opportunities for reuse and recycling. This included an analysis of strategic competitive advantages in the chain, barriers to market entry, barriers to doing business, cooperation between actors, regulatory impacts, and management and coordination functions in the chain. Most importantly, emphasis was placed on identifying barriers and opportunities for integrating open innovation processes. The analysed data were collected through a literature review of secondary sources and through the qualitative method of in-depth interviews. More than half of the interviewees saw open innovation as a strong competitive advantage, but at the same time cited several barriers. We identified opportunities to improve the value chain in the areas of digitalization, resource management, the circular economy, by strengthening research and development activities, and by connecting actors in the chain. The opportunities for the further development of value chains in wood construction are therefore significant. However, the implementation of the aforementioned solutions requires coordinated regional policies and solutions at national (and European) level.

Keywords: value chain, wood construction, open innovation, circular economy, digitalization

1 UVOD

1 INTRODUCTION

Panoga lesene gradnje lahko pripomore k zmanjševanju emisij toplogrednih plinov in k vzpostavitvi nizkoogljičnega in krožnega gospodarstva, kot je prikazano na sliki (slika 1). Pri izdelavi lesene konstrukcije se porabi 20 %–50 % manj energije kot pri izdelavi železobetonske konstrukcije

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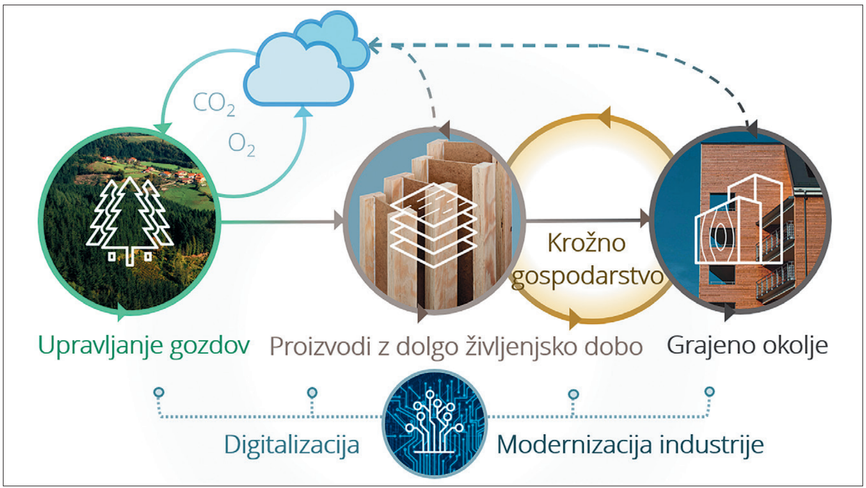
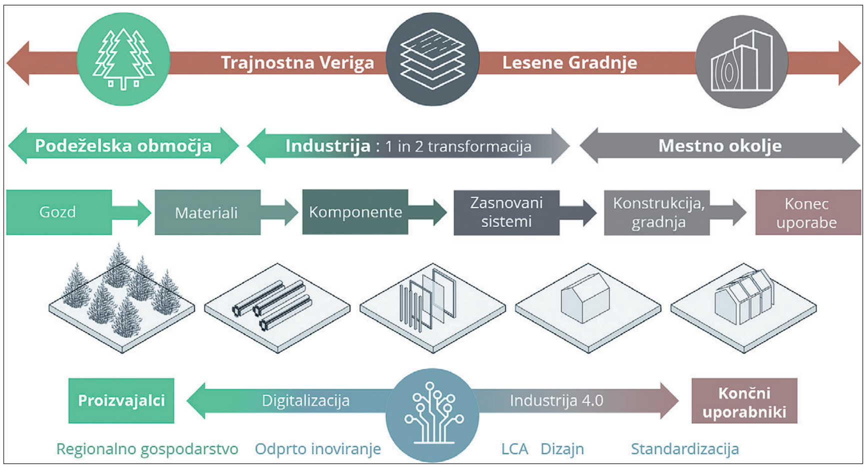


Slika 1. Skladiščenje ogljika s trajnostno rabo lesa v grajenem okolju (Kies et al., 2022).
Figure 1. Carbon storage through the sustainable use of wood in the built environment (Kies et al., 2022).

(Hurmekoski, 2017). Če upoštevamo skladiščen ogljik v lesenih zgradbah, je skupen ogljični odtis lesa pravzaprav negativen in je kot substitut železobetonskim konstrukcijam veliko bolj prijazen do okolja. Leskinen in sodelavci (2018) so ugotovili, da vsak kubični meter lesa, ki je uporabljen kot substitut nelesnim energetsko potratnim proizvodom (npr. železobetonska konstrukcija), zmanjša emisije CO_2 za 273 kg.

Evropskim gozdnim območjem se biomasa v povprečju poveča za 2,8 % letno (Lanvin et al., 2020). Glede na trenutno stanje gozdnih virov in njihovega prirastka imamo v Evropi veliko priložnost zmanjšati CO_2 emisije z uporabo lesa v gradbeništvu. Eden izmed projektov na evropski ravni, ki preučujejo možnosti povečanja rabe lesa v gradbeništvu, je tudi projekt Basajaun (Cordis, 2023), v okviru katerega so in še bodo razviti številni inovativni produkti in rešitve tudi na področju ponovne uporabe lesa, vključno z vzpostavitvijo platforme za odprto inoviranje v lesni industriji. Ta bo služila odprtemu inoviranju na regionalni in mednarodni ravni tudi po koncu projekta. Za doseganje potenciala lesa kot trajnostnega materiala v gradbeništvu je potrebna visoka osredotočenost na regionalne vrednostne verige lesene gradnje in vzpostavitev inovativnega ekosistema, ki lahko ustvari potrebne rešitve, kot je prikazano na spodnji sliki (slika 2).

Ta celostni pristop zahteva vzpostavitev vrednostnih verig, ki povezujejo podeželske in urbane regije, od gozda do ljudi, ki si želijo trajnosten način bivanja. V projekt Basajaun je bila vključena študija petih različnih regij, njihovih vrednostnih verig lesene gradnje ter obstoječe regionalne podpore za odprto inoviranje (Severna Ostrobotnija in Severna Karelija na Finskem, Nova Akvitanija v Franciji, Zahodna Pomeranija na Poljskem in dežela Baskija v Španiji). Cilj tega prispevka je poglobljena analiza vrednostne verige lesene gradnje Nove Akvitanije v Franciji.



Slika 2. Vloga vrednostne verige lesene gradnje pri trajnostnem razvoju podeželskih in urbanih regij (Kies et al., 2022).
Figure 2. The role of the wood construction value chain in the sustainable development of rural and urban regions (Kies et al., 2022).

2 MATERIALI IN METODE
2 MATERIALS AND METHODS
2.1 ANALIZA VREDNOSTNE VERIGE
2.1 VALUE CHAIN ANALYSIS

Analiza vrednostne verige je študija industrij, organiziranih okoli določenih izdelkov in njihovih trgov. Koncept vrednostne verige se uporablja kot model za opis družbenoekonomske realnosti. Konvencionalni elementi analize vrednostne verige vključujejo shemo vrednostne verige, tržno analizo in oceno upravljanja oziroma vodenja verige ter dinamiko sodelovanja ali konkurenčnosti med akterji. Metodologija analize vrednostne verige je povzeta po Priročniku o trajnostnem razvoju vrednostnih verig–ValueLinks2.0, GIZ (Springer Heinz, 2018a). Osnovni elementi analize vrednostne verige so:

- strukturna analiza,
- ekonomska analiza,
- analiza okoljskih dejavnikov in vplivov,
- analiza družbenih dejavnikov in vplivov.

Vrednostno verigo je možno analizirati zelo na široko, zato je priporočljivo že pred začetkom analize določiti obseg raziskave in pridobivanja informacij. V tej raziskavi je večina pozornosti namenjena strukturni analizi vrednostne analize, ki vključuje:

- identifikacijo vseh udeleženih v vrednostni verigi lesene gradnje od podjetij do institucij in analiza vseh faz vrednostne verige od gozda do končnih proizvodov, vključno z možnostmi ponovne uporabe in recikliranja,
- analizo interakcij in sodelovanja med akterji, prepoznavanje njihovih vhodnih in izhodnih produktov, procesov, podatkovnih izmenjav ter vodstvenih in koordinacijskih vlog v verigi,
- risanje sheme–diagrama vrednostne verige v lokalni regiji Novi Akvitaniji v Franciji.

Za risanje sheme vrednostne verige je značilnih osem generičnih elementov. Pet elementov predstavlja osnovno shemo na mikro ravni, ki prikazujejo pot produktov na končne trge (Springer Heinz, 2018a):

- produkti oziroma skupina produktov, ki definirajo vrednostno verigo,
- končni trgi, na katerih so produkti trženi,
- serija faz, skozi katere je produkt proizveden in plasiran na končne trge,
- podjetja, ki izvajajo poslovne aktivnosti,
- poslovne povezave med podjetji in ostalimi akterji v verigi.

V shemo so lahko vključeni tudi preostali trije elementi, ki vplivajo na osnovne faze verige:

- izbrane poslovne povezave s podizvajalci in ponudniki operativnih storitev,
- ponudniki podpornih storitev v panogi,
- javne agencije, ki opravljajo regulativne funkcije na makro ravni.

2.2 KVALITATIVNA RAZISKAVA
2.2 QUALITATIVE RESEARCH

Kvalitativna raziskava je bila izvedena z globinskimi intervjuji akterjev v vrednostni verigi lesene gradnje. Intervjuji so potekali prek videokonferenčnih povezav in so trajali približno eno uro. Za ta namen smo oblikovali anketni vprašalnik z odprtimi in zaprtimi tipi vprašanj. Vprašanja so zajemala dejavnike, ki so povezani z vrednostno verigo lesene gradnje:

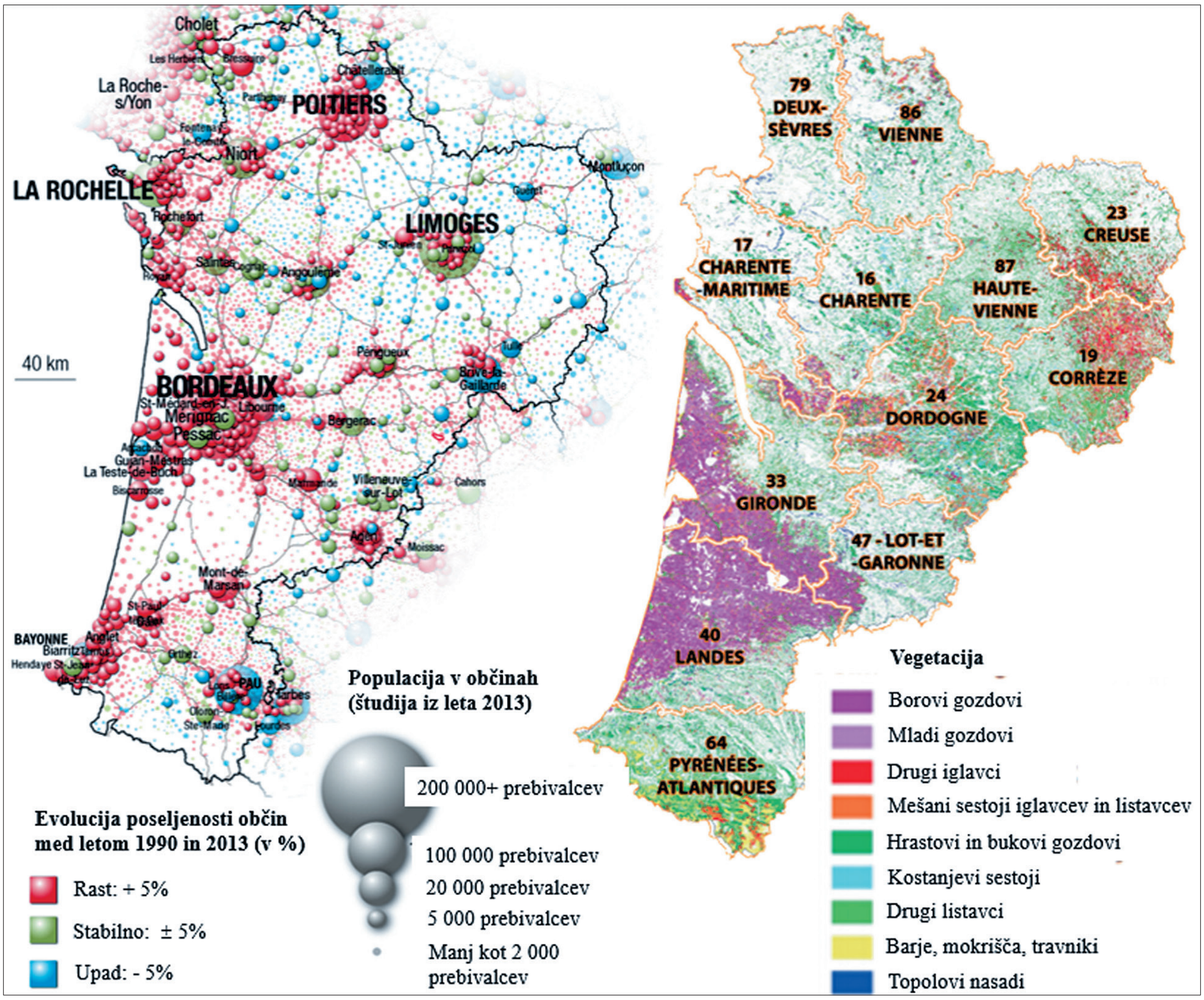
- ovire za vstop v vrednostno verigo lesene gradnje,
- strateške konkurenčne prednosti v verigi lesene gradnje,
- management vrednostne verige ter sodelovanje med deležniki v vrednostni verigi (interakcije, stopnja izmenjave informacij, različni načini sodelovanja …),
- ozka grla v vrednostni verigi lesene gradnje,
- priložnosti za nadgradnjo vrednostne verige lesene gradnje.

Na vprašanja zaprtega tipa je bilo možno odgovoriti z odgovori na petstopenjski Likertovi lestvici ali z izbiro odgovora DA in NE. To je omogočalo primerjanje in osnovo za kvantitativno analizo nekaterih pomembnih dejavnikov. Vprašanja odprtega tipa pa so omogočala poglobljen intervju, s poudarkom na problemih in rešitvah v vrednostni verigi. Odgovori na odprta vprašanja so bili sistematično zbrani, analizirani in povzeti z najpomembnejšimi ugotovitvami.

Opravljenih je bilo 14 intervjujev. Intervjuvanci so bili izbrani z namenskim vzorčenjem, saj je tema vprašalnika zahtevala strokovna znanja intervjuvancev, glede na njihov tip in položaj v vrednostni verigi lesene gradnje. V raziskavo so bili vključeni strokovnjaki različnih področij po celotni vrednostni verigi, od faze pridobivanja surovin do končne uporabe in recikliranja. Razlikovali smo predvsem med podjetji, ki neposredno ustvarjajo produkte v verigi lesene gradnje, in združbami, ki opravljajo podporne storitve. Intervjuje smo izvedli v obdobju med 01. 08. 2020 in 10. 10. 2020. Odstotek intervjuvancev iz podjetij je bil 61 %, medtem ko je bilo 39 % intervjuvancev iz drugih inštitucij. Odgovore smo pridobili od podjetij, katerih dejavnost je vezana na gozdarstvo, primarno in sekundarno proizvodnjo, gradnjo in konstruiranje lesenih zgradb, podjetij, ki ponujajo različne storitve (arhitekti, oblikovalci, trgovci), ter podjetij, ki se ukvarjajo z rušenjem objektov, obnovo in recikliranjem. Odgovori od tehnoloških in raziskovalnih inštitutov, univerz ter ostalih združb (poslovni grozdi, industrijska združenja in zadruge) pa znašajo 39 % ostalih odgovorov.

3 REZULTATI IN RAZPRAVA
3 RESULTS AND DISCUSSION
3.1 NOVA AKVITANIJA
3.1 NEW AQUITAINE

Nova Akvitanija se nahaja na jugozahodu Francije. Je največja administrativna regija in največja regija po površini v Franciji. Razteza se na 84.036 km², kar predstavlja eno osmino ozemlja Francije. Ima približno šest milijonov prebivalcev (Comparateur, 2021). Slika 3 prikazuje razmerja med urbanimi, podeželskimi ter gozdnatimi območji na tem območju. Na levem zemljevidu so podeželska območja označena z najmanjšimi mehurčki,



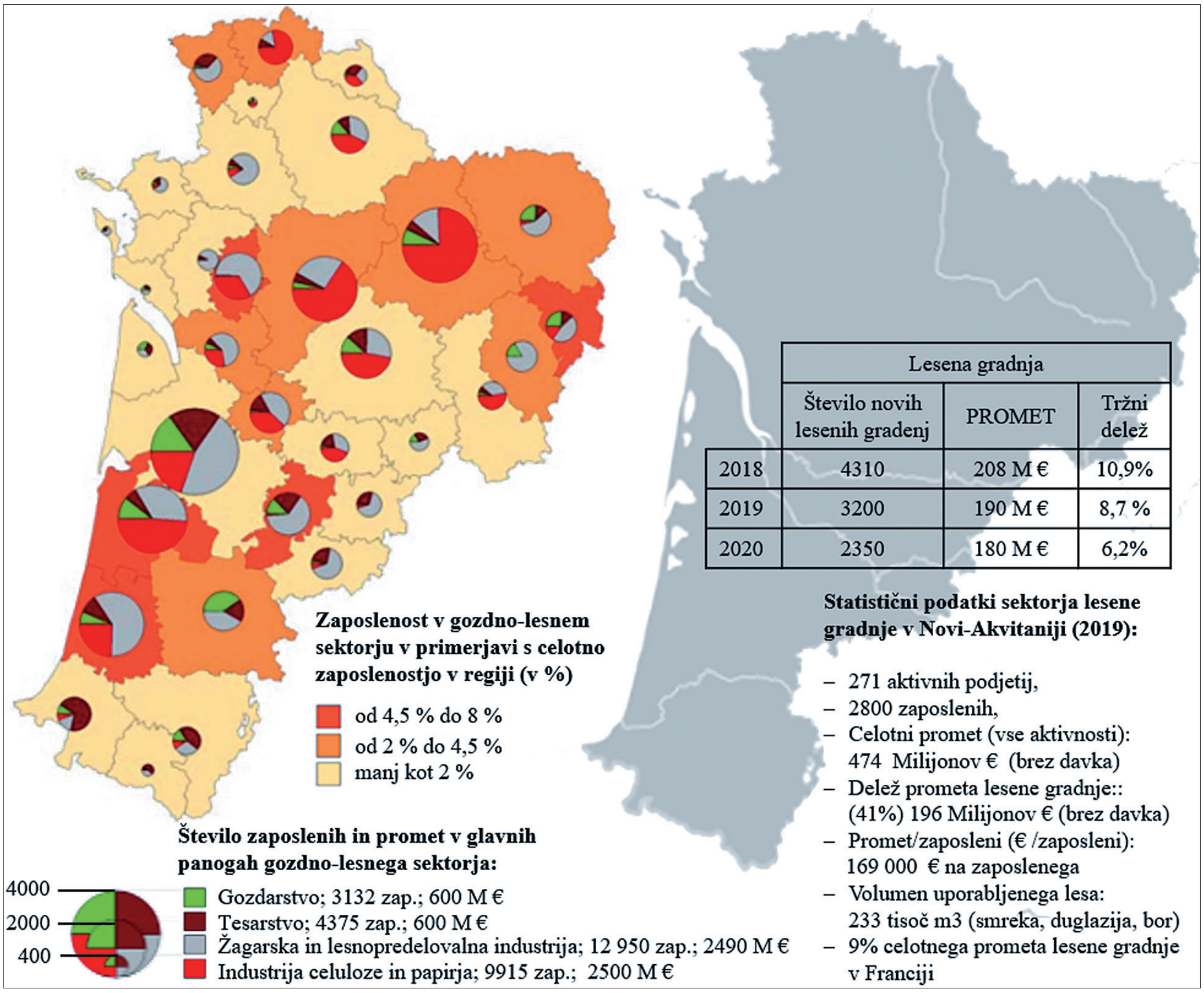
Slika 3. Dinamika urbanih in podeželskih ter gozdnatih območij (Memento, 2020: 5 cit. po Cartographies départementales IGN de 2000 à 2010).

Figure 3. Dynamics of urban, rural and forested areas (Memento, 2020: 5 cit. Cartographies départementales IGN de 2000 à 2010).

ki označujejo območja z manj kot 2.000 prebivalci. Urbana območja so označena z večjimi mehurčki. Regija ima 25 večjih urbanih območij. Povprečna gostota poseljenosti znaša 70,3 prebivalcev/km². Gironde ima najvišjo gostoto poseljenosti s 165,8 prebivalci/km² (Nouvelle Aquitaine, 2023). V referenčnem obdobju od 2018 do 2021 je regija zabeležila 1,1 % letno rast populacije. Rast populacije je še posebej očitna na priobalnih in urbanih središčih, ki so ena izmed najbolj atraktivnih v Franciji. Večji upad števila prebivalcev pa je opazen v podeželskih občinah na vzhodu (označeno z majhnimi modrimi mehurčki).

Gozdna površina v Novi Akvitaniji pokriva 2,8 milijona hektarjev ozemlja, kar predstavlja 33 % njenega ozemlja. V Novi Akvitaniji je 90 % gozdov v lasti zasebnih lastnikov. Celotna lesna zaloga v regiji znaša 384 milijonov kubičnih metrov (v povprečju znaša 136 m³/ha). Listavci predstavljajo 62 % lesne zaloge. Med listavci so najbolj razširjene različne vrste hrasta, ki skupno predstavljajo 29 % gozda v regiji. Iglavci predstavljajo preostalih 38 % lesne zaloge. Tako imenovani Landes (označen z vijolično barvo na desnem zemljevidu) je največji umetno zasajeni gozd v zahodni Evropi. Pokriva približno 1,5 milijona hektarjev.

Primorski bor (*Pinus pinaster*), ki raste na tem območju, predstavlja skoraj četrtino regionalnega gozda. Duglazija (*Pseudotsuga menziesii*) in smreka (*Picea abies*) sta drugi pomembni vrsti iglavcev in



Slika 4. Velikost sektorja lesene gradnje v primerjavi z gozdno-lesnim sektorjem v Novi Akvitaniji (levi zemljevid–Memento, 2020 cit. po INSEE – Clap, in desni zemljevid–Observatorie, 2020).

Figure 4. The size of the wood construction sector compared to the forest-wood sector in New Aquitaine (left map–Memento, 2020 cit. INSEE–Clap, and right map–Observatorie, 2020).

skupaj predstavljata 10 % gozdne površine v regiji. Skupna količina lesne biomase se je med letoma 1987 in 2012 nenehno povečevala. Z izjemo primorskega bora se je lesna zaloga vseh ostalih vrst povečala. Na glavnem nahajališču primorskega bora, Landes de Gascogne, se je po dveh neurjih Martin (1999) in Klaus (2009) njegova zaloga zmanjšala za skoraj polovico (PRFB, 2020).

Nova Akvitanija je vodilna regija v gozdarstvu, žagarstvu in proizvodnji končnih produktov v Franciji. Posekan les v Novi Akvitaniji predstavlja četrtino celotnega poseka v Franciji. Posek primorskega bora pa znaša kar 90 % celotnega poseka te vrste v Franciji. Letni posek okoli 10 milijonov m³/leto je že vrsto let bistveno nižji od letnega prirastka gozdne biomase, ki znaša 16,8 milijona m³/leto. Les iglavcev predstavlja 70 % posekane količine. Preostalih 30 % (1,6 milijona m³) poseka na leto predstavlja les listavcev.

3.2 VREDNOSTNA VERIGA LESENE GRADNJE V NOVI AKVITANIJI

3.2 WOOD CONSTRUCTION VALUE CHAIN IN NEW AQUITAINE

Gozdno-lesni sektor v Franciji zaposluje 440.000 ljudi, v Novi Akvitaniji pa je v tem sektorju zaposlenih 30.000 ljudi, kar predstavlja 1,6 % zaposlenih v regiji. V to statistiko so vključeni le zaposleni iz štirih glavnih panog sektorja (slika 4): gozdarstvo, žagarska in lesnopredelovalna industrija, tesarstvo ter industrija celuloze in papirja.

V gozdarstvu, sečnji in tesarstvu prevladujejo manjša podjetja, medtem ko v industriji celuloze in papirja delujejo predvsem večja podjetja. Industrija celuloze in papirja v 256 podjetjih zaposluje 10.000 ljudi. Na drugi strani žagarska in lesnopredelovalna industrija ustvarjata največ zaposlitev v sektorju. Več kot 50 % zaposlitev se nahaja na podeželskih območjih, kjer lahko gozdno-lesni sektor zaposluje tudi do 8 % lokalnega prebivalstva. Lesnopredelovalni sektor je podprt s strani organizacij, ki povezujejo raziskovalno akademsko delo in industrijo. V Novi Akvitaniji je več kot 60 ustanov, katerih aktivnosti so povezane z izobraževanjem, usposabljanjem, povezovanjem, raziskovanjem, inoviranjem in razvojem gozdno-lesnega sektorja. Tudi te ustanove zaposlujejo večje število ljudi. Če upoštevamo tudi povezane dejavnosti in sektorje, gozdno-lesni sektor zaposluje 56.000 ljudi (PRFB, 2020). Lesnopredelovalni sektor v Novi Akvitaniji ustvarja več kot 10 milijard evrov letnega prometa. K tej vrednosti industrija celuloze in papirja prispeva 40 %, lesnopredelovalna industrija 30 % (proizvodnja furnirja, plošč, parketa, okvirjev, lesene embalaže in raznih predmetov iz lesa), žagarska industrija 12 %, gozdarske in tesarske dejavnosti pa vsaka po 9 %. Med tesarske dejavnosti spadajo tudi dejavnosti in aktivnosti, povezane z leseno gradnjo (PRFB, 2020**)**. Sektor lesene gradnje pa vključuje tudi ostale dejavnosti.

Lesena gradnja se nanaša na vse konstrukcijske tehnike na osnovi lesa (skeletna gradnja, leseni obodi, stebri in nosilci iz lesa, masivne lepljene plošče, tradicionalna lesena gradnja z masivnim lesom, ipd.), ki se uporabljajo za izdelavo bivanjskih ali nebivanjskih stavb. To pa ne zajema zunanje

Preglednica 1. Tržni segmenti in število novih lesenih gradenj v Novi Akvitaniji (Observatorie, 2020).
Table 1. Market segments and number of new wood constructions in New Aquitaine (Observatorie, 2020).

Tržni segment	Število novih lesenih gradenj v Novi Akvitaniji (2019)	Število vseh novih gradenj v Novi Akvitaniji (2019)	Delež lesene gradnje v primerjavi z vso novo gradnjo v Novi Akvitaniji	Delež lesene gradnje Nove Akvitanije v primerjavi z vso ostalo leseno gradnjo v Franciji (2019)
Razpršene individualne hiše	618	13.130	4,7 %	9,2 %
Individualne hiše v naseljih	588	3.228	18,2 %	10,3 %
Individualne hiše	**1.206**	**16.358**	**7,4 %**	**9,4 %**
Kolektivna stanovanja	**589**	**11.573**	**5,0 %**	**4,3 %**
Vse nastanitve	**1.795**	**28.131**	**6,4 %**	**6,3 %**
Nadzidki / prizidki	**938**	**3.162****	**29,7 %**	**27,5 %**

toplotne izolacije stavb. Podjetja poleg osnovnih aktivnosti pogosto izvajajo tudi druge aktivnosti, ki pa niso direktno vezane na leseno gradnjo, oziroma vključujejo druge materiale (instalacija zunanjih in notranjih stenskih oblog, instalacija zunanje toplotne izolacije ter ostale instalacije). V ta namen izvedena raziskava prikazuje točen delež prihodkov, ki so vezani le na osnovne aktivnosti lesene gradnje (slika 4, desna stran). Poleg tega je opredeljen tudi tip, tržni delež in število novih lesenih gradenj v regiji Nova Akvitanija (preglednica 1).

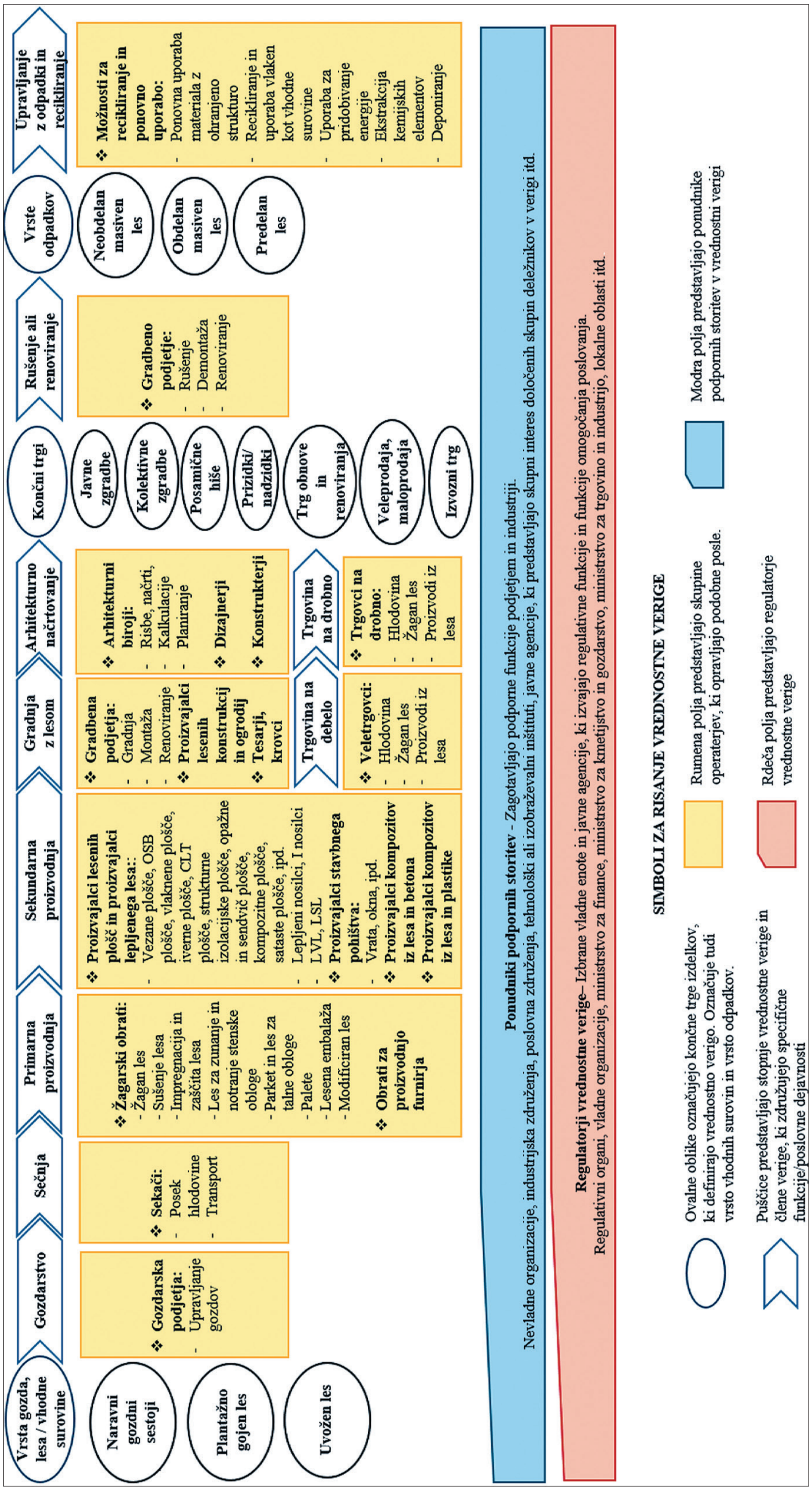
Gradbeni sektor v Franciji zaposluje 1,12 milijona ljudi v 403.000 podjetjih, ki ustvarjajo 148 milijard prometa (pred obdavčitvijo). Lesena gradnja predstavlja 3 % prometa in 2,5 % delovne sile v primerjavi s celotnim gradbenim sektorjem v Franciji (Enquete Nationale, 2021). Po krizi v gradbenem sektorju leta 2014 in 2016 je lesena gradnja v Franciji zabeležila visoko rast v letu 2018. V letu 2020 je imela zdravstvena in ekonomska kriza velik vpliv na sektor lesene gradnje v Franciji, saj je povzročila težave v dobavnih verigah, zaprtja in splošno nepredvidljivost. Leta 2020 je v Franciji 1978 podjetij doseglo 4,1 milijarde € prometa v sektorju lesene gradnje. Podjetja so osredotočena predvsem na nove gradnje, ki predstavljajo 75 % njihovega prometa (3,1 milijarde € brez DDV v letu 2020). Med novimi gradnjami so stanovanjske gradnje njihov glavni trg, kjer so v letu 2020 ustvarile za 1,89 milijarde € prometa. Vzdrževalna in obnovitvena dela so v letu 2020 znašala 1,02 milijarde € prometa, kar je 5 % manj kot v letu 2018 (Enquete Nationale, 2021).

Med regijami zasledimo odstopanja, ko primerjamo podatke o upadu ali rasti prometa v sektorju lesene gradnje. V Novi Akvitaniji so bili prihodki leta 2020 (180 milijonov €) za 9 % manjši kot v letu 2019 (196 milijonov €) in za 13,5 % manjši kot v letu 2018 (208 milijonov €). V Novi Akvitaniji je vsako leto vloženih okoli 40.000 gradbenih dovoljenj in zgrajenih 7,78 milijona m² stavbnih površin. Od 6 %–10 % teh stavbnih površin je zgrajenih iz lesa. V letu 2020 je bil delež lesene gradnje le 6,2 %, leta 2018 pa 10,9 %. V povprečju lesena gradnja porabi okoli 0,3 m³ lesa na m² grajene površine. Na podlagi tega razmerja lahko ocenimo, da trg lesene gradnje v Novi Akvitaniji porabi 233.000 m³ lesa (PRFB, 2020). Delež lesa za leseno gradnjo je torej majhen, če ga primerjamo s količino posekanega (10 milijonov m³) in žaganega (2 milijona m³) lesa v regiji. Poleg tega je velik delež lesenih proizvodov in lesa, uporabljenega za gradnjo, uvožen. Lokalna proizvodnja torej ne proizvaja zadostnih količin ali pa ne dosega želene kakovosti za potrebe lokalnega sektorja lesene gradnje.

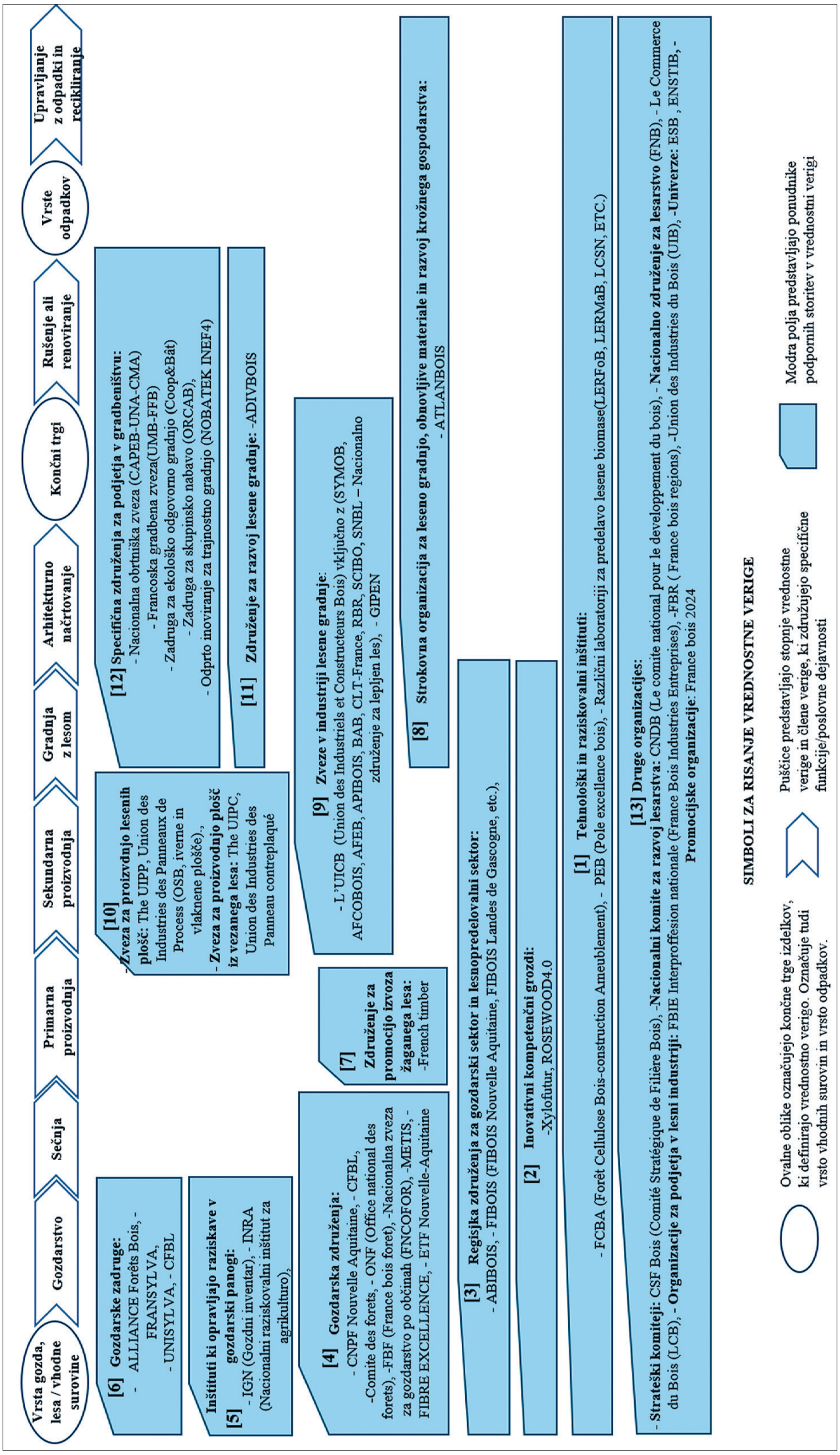
Statistika uporabe različnih konstrukcijskih sistemov je zbrana iz vseh regij v Franciji, zato so možna regionalna odstopanja. Kljub temu, da se delež uporabe skeletne gradnje zmanjšuje, ta ostaja najbolj uporabljena konstrukcijska tehnika ne glede na trg (83 % pri gradnji enostanovanjskih hiš, 68 % pri gradnji večstanovanjskih stavb in 69 % pri gradnji terciarnih zgradb). Delež uporabe lepljenih nosilcev in nosilnih stebrov se je na trgu enostanovanjskih hiš v letu 2020 povečal iz 8 % na 10 % (v primerjavi z 2018). V enakem obdobju se je povečal tudi delež uporabe lesenih lepljenih nosilcev pri gradnji terciarnih stavb, iz 17 % v letu 2018 na 20 % v letu 2020. Delež uporabe lepljenih plošč iz masivnega lesa (CLT), ki ima veliko vlogo pri gradnji večstanovanjskih stavb, pa je narasel z 10 % v letu 2018 na 15 % v letu 2020 (Enquete Nationale, 2021).

Gozd ustvarja ogromno ekonomske dodane vrednosti in je prvi člen vrednostne verige lesnopredelovalne industrije, ki jo tvorita primarna in sekundarna predelovalna industrija. Slika 5 prikazuje osnovno strukturo vrednostne verige lesene gradnje. V vrednostni verigi je prisotnih več različnih akterjev, ki pa opravljajo različne poslovne aktivnosti (akter v vrednostni verigi je splošni izraz za vse posameznike, podjetja in javne agencije, povezane z vrednostno verigo, zlasti operativna podjetja, ponudnike operativnih storitev in ponudnike podpornih storitev). Ponudniki podpornih storitev predstavljajo enega od pomembnejših členov v razvojnih in raziskovalnih procesih ter v procesih inoviranja. Skupine ponudnikov podpornih storitev lahko obravnavamo kot ključen člen v procesih prihodnje platforme odprtega inoviranja. Delimo jih lahko v dve splošni skupini (Springer Heinz, 2018a):

- Inštituti za raziskave in usposabljanje, ter druge javne inštitucije kot npr. univerze. Podjetjem ponujajo informacije in druge podporne storitve ter asistirajo podjetjem pri določenih aktivnostih (v nadaljevanju – raziskovalni inštituti).
- Industrijska in poslovna združenja, ki zagotavljajo podporne storitve skupinam podjetij ali celotni vrednostni verigi. Njihove aktivnosti



Slika 5. Vrednostna veriga lesene gradnje.
Figure 5. Wood construction value chain.



Slika 6. Inštitucije, ki izvajajo podporne storitve v vrednostni verigi lesene gradnje.
Figure 6. Institutions that provide support services in the wood construction value chain.

vključujejo spodbujanje in promocijo izvoza, zagovarjanje skupnih interesov, vplivanje na regulativne odločitve itd. (v nadaljevanju – poslovna združenja in organizacije).

Med podporne storitve uvrščamo (Springer Heinz, 2018b):

- poklicna usposabljanja in izobraževanja, specifična za sektor,
- aplikativne raziskave, razvoj tehnologije in inovacij,
- objave tržnih podatkov kot so proizvedene in prodane količine, cene ter objava drugih splošnih informacij sektorja,
- uporabo tehničnih prostorov in zmogljivosti (npr. testni prostori raziskovalnih inštitutov, laboratoriji, itd.),
- promocijo na domačih in tujih trgih, sejemske in razstavne aktivnosti,
- odnose z javnostjo in skupno trženje izdelkov,
- lobiranje in zagovarjanje skupnih interesov celotne skupnosti v vrednostni verigi.

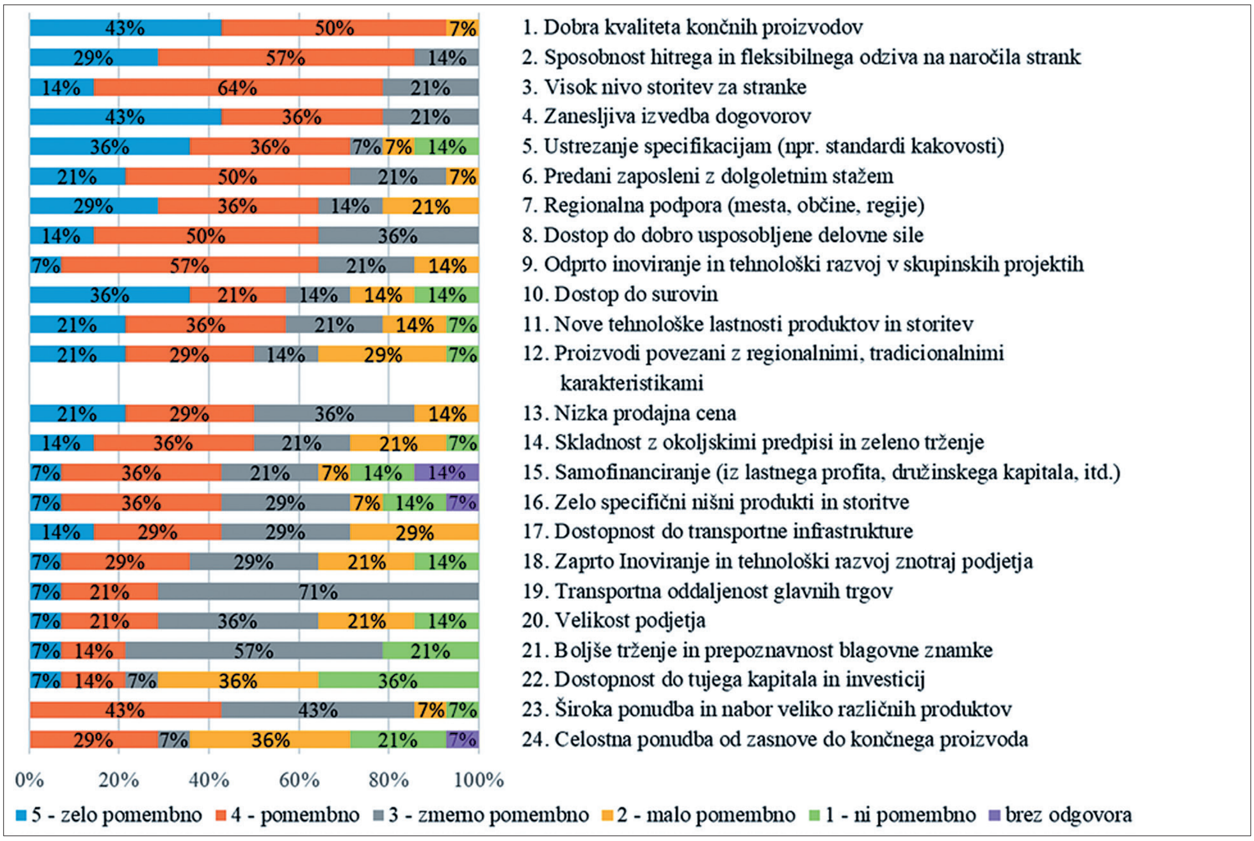
V Franciji je veliko različnih ponudnikov podpornih storitev, ki s svojimi aktivnostmi podpirajo celotno verigo ali pa so osredotočeni zgolj na določene faze v verigi. Združbe so po kategorijah zbrane v pravokotnikih glede na tip dejavnosti, podobnost njihovih aktivnosti in karakteristik ter obseg delovanja (slika 6). Širina modrih pravokotnikov predstavlja okviren obseg dejavnosti in razvojnih programov posameznih skupin organizacij. Skupine združb v najširših modrih pravokotnikih (primer pravokotnik s številko 1) pokrivajo celotno vrednostno verigo in so na voljo vsem podjetjem v verigi. Nasprotno, ožji pravokotniki nakazujejo osredotočenost na le nekatere faze v verigi. Vsak pravokotnik je označen s številko in obrazložen. Vloga inštitutov [1] [5], ki so eden najpomembnejših nosilcev vrednostne verige, je lahko povezana s tehnološkimi, inovacijskimi, razvojnimi, izobraževalnimi ali raziskovalnimi aktivnostmi. Vključeni so v več faz vrednostne verige, od lastnikov gozdov do konca uporabe izdelkov in recikliranja. Poslovna združenja in grozdi so še ena skupina podpornikov vrednostne verige. Izvajalci podpore, ki spadajo v to splošno skupino, so: poslovna združenja [2] [7] [11], različna večdisciplinska združenja za gozdarstvo in leseno gradnjo [3] [4] [12], različne zadruge in zveze [6] [9] [10] ter druge razvojne [8] in industrijske [9] organizacije. Običajno ti poslovni grozdi in združenja predstavljajo poseben del vrednostne verige. V nekaterih primerih pokrivajo le eno stopnjo vrednostne verige, na primer gozdarstvo [6], proizvodnjo plošč [10]. Po drugi strani pa nekatera združenja izvajajo dejavnosti v več členih vrednostne verige [2] [3] [8] [9]. Delujejo lahko na regionalni, nacionalni ali celo mednarodni ravni. Na shemi so prikazane tudi druge združbe [13]. Večina jih predstavlja specializirane enote javne uprave, ki zagotavljajo informacijske in druge podporne storitve gospodarstvu ter pomoč podjetjem. Predvsem odbori so zadolženi za promocijo in komuniciranje vzdolž celotne vrednostne verige. Odbori usklajujejo dejavnosti vzdolž celotne vrednostne verige in posredujejo skupne politike.

3.3 KOMPETENČNE PREDNOSTI PODJETIJ V VREDNOSTNI VERIGI LESENE GRADNJE

3.3 COMPETITIVE ADVANTAGES OF COMPANIES IN THE WOOD VALUE CHAIN

Konkurenčna prednost je lastnost, ki podjetju omogoča, da je boljše od svoje konkurence. Ozko gledano se podjetja med seboj borijo za čim boljši konkurenčni položaj, imamo pa tudi primere, ko lahko podjetja povečajo svojo konkurenčnost s sodelovanjem z ostalimi podjetji. Povezovanje na nivoju celotnih vrednostnih verig je zelo pomembno in lahko omogoča visoko konkurenčno prednost tako verige kot celote kot tudi njenih posameznih delov. Za večjo konkurenčnost vrednostnih verig so zelo pomembni tudi zunanji izvajalci določenih storitev.

Za oceno relativne pomembnosti različnih dejavnikov, ki lahko podjetjem pomagajo obdržati in izboljšati konkurenčen položaj na trgu in v vrednostni verigi (npr. pri določanju svojih cen ali pri pogajanjih), smo preučili 24 kompetenčnih dejavnikov. Na sliki 7 so prikazane najpomembnejše in manj pomembne kompetenčne prednosti, ki jih je dobro razviti za boljši konkurenčni položaj. Med najbolje ocenjene z ocenami 5 (zelo pomembno) in 4 (pomembno) spadajo: visoka kakovost končnih proizvodov, sposobnost hitrega in fleksibilnega odziva na naročila strank, visok nivo storitev za stranke, zanesljiva izvedba dogovorov, ustrezanje specifikacijam (npr. standardi kakovosti) ter predani zaposleni z dolgoletnim stažem. Omenjene kompetenčne dejavnike je vsaj dve tretjini intervjuvancev ocenilo s 5 ali 4. Visoko oceno je dobil tudi dejavnik, opredeljen kot ‘’Odprto inoviranje in tehnološki razvoj v



Slika 7. Kompetenčne prednosti podjetij v vrednostni verigi lesene gradnje (n = 14).
Figure 7. Competitive advantages in wood construction value chain (n = 14).

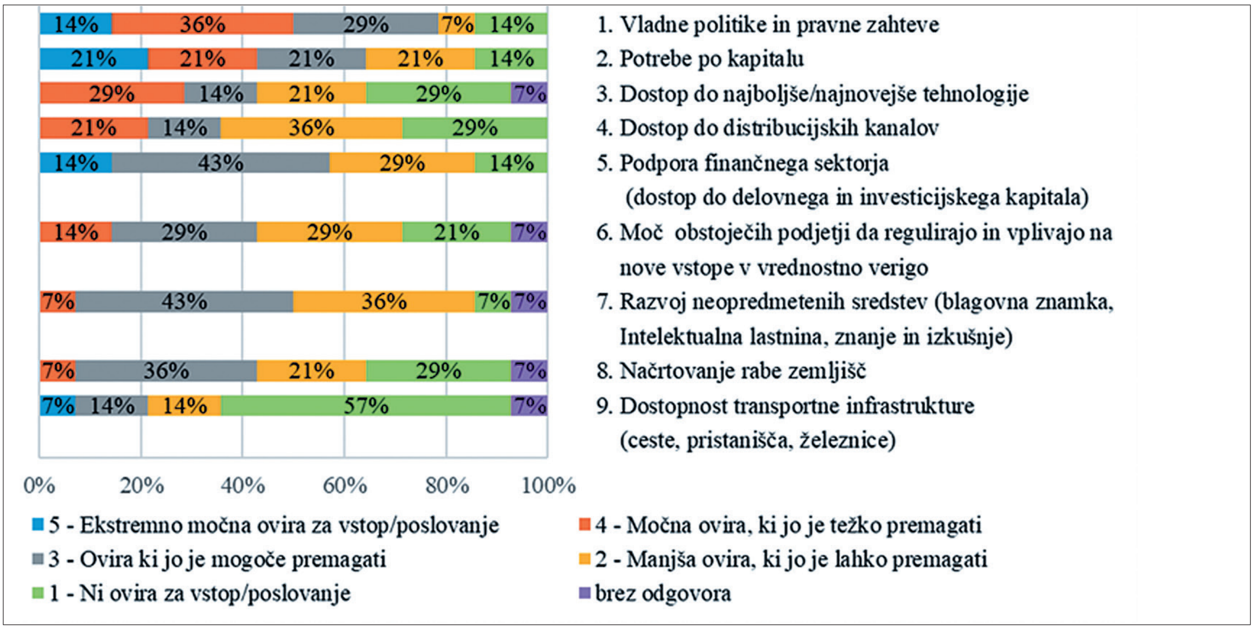
skupinskih projektih'', kjer 64 % anketirancev meni, da je ta konkurenčna prednost zelo pomembna oz. pomembna. Konkurenčni dejavnik ''zaprto inoviranje in tehnološki razvoj znotraj podjetja'' je bil ocenjen slabše, kjer je le 36 % anketirancev mnenja, da je ta konkurenčna prednost zelo pomembna ali pomembna. Glede na rezultate lahko potrdimo, da kompetenčna prednost podjetij ni zagotovljena zgolj z vstopom v proces odprtega inoviranja, saj obstaja veliko dejavnikov, ki pogojujejo uspeh, pri čemer so anketiranci navedli veliko težav, ovir in dvomov, zaradi česar je v sektorju lesene gradnje malo uspešno izvedenih projektov s pristopom odprtega inoviranja.

3.4. VSTOPNE OVIRE IN OZKA GRLA V VREDNOSTNI VERIGI LESENE GRADNJE
3.4 BARRIERS TO ENTRY AND BOTTLENECKS IN THE WOOD CONSTRUCTION VALUE CHAIN

Anketiranci so ocenjevali devet potencialnih ovir, ki lahko omejujejo poslovanje ali vstop novih podjetij v vrednostno verigo, prav tako pa so lahko navedli tudi druge ovire. Ocene kažejo, da večina teh ovir ni velika, kar je razvidno na sliki 8. Izjema so le ''vladne politike in pravne zahteve'' in ''potrebe po kapitalu'', katere je polovica anketirancev ocenila kot ekstremno močni oziroma močni oviri, ki ju je težko premagati.

Odgovori na odprta vprašanja so razkrili ostala ozka grla, ovire in izzive:

- Pomanjkanje skupnih strategij, zlasti med primarno in sekundarno proizvodnjo. Problem je tudi ta, da imajo deležniki veliko različnih mnenj in strategij uporabe virov. Veriga bi morala vzpostaviti optimalno sortiranje in rabo virov v proizvodnih procesih.
- Žagan les pogosto ne izpolnjuje zahtev po kakovosti, zato žagarski proizvodi niso primerni za robotizirano delavnico.
- Dolgi postopki in pomanjkanje zmogljivosti za hitrejše ocenjevanje proizvodov in procesov pri pridobivanju certifikatov.
- Pomanjkanje recikliranja in možnosti recikliranja gradbenih materialov. Majhna ponudba re-



Slika 8. Vstopne ovire in ovire pri poslovanju v vrednostni verigi lesene gradnje (n = 14).
Figure 8. Barriers to entry and barriers to doing business in the wood construction value chain (n =14).

cikliranih proizvodov za leseno gradnjo. Krožno gospodarstvo ni vzpostavljeno.

- Zelo težko je dobiti sredstva za podjetje, ki vstopa na novo. Nova podjetja potrebujejo več podpore.
- Mala in srednja podjetja so pogosto omejena zaradi nepoznavanja standardov. Imajo zmogljivosti, vendar zaradi svoje strukture in pomanjkanja znanja ne morejo izkoristiti polnega potenciala.
- Predpisi so med glavnimi mehanizmi za blokiranje inovacij v Franciji. Uradi težko izdajo odobritev inovativnih rešitev. Težave se pojavljajo tudi pri visokih stroških razvoja in stroških testiranja.
- Izobraževanje gradbenih inženirjev se osredotoča na tradicionalne konstrukcijske procese in ne vključuje študija avtomatizacije, robotike, tovarniškega načrtovanja, digitalizacije itd. Ta znanja bi omogočila proizvodnjo, primerljivo z avtomobilsko industrijo. Višja kot je stopnja industrijske prefabrikacije in modularizacije, boljša je konkurenčnost lesa kot konstrukcijskega materiala.
- Pomanjkanje izkušenih projektantov, mojstrov in vodij gradbišč je prepoznano kot problem. Izobraževalni programi bi se morali bolj osredotočiti na vodenje procesov v leseni gradnji.

Veliko težav se torej pojavlja pri vodenju in upravljanju vrednostnih verig ter pri sodelovanju in pretoku informacij.

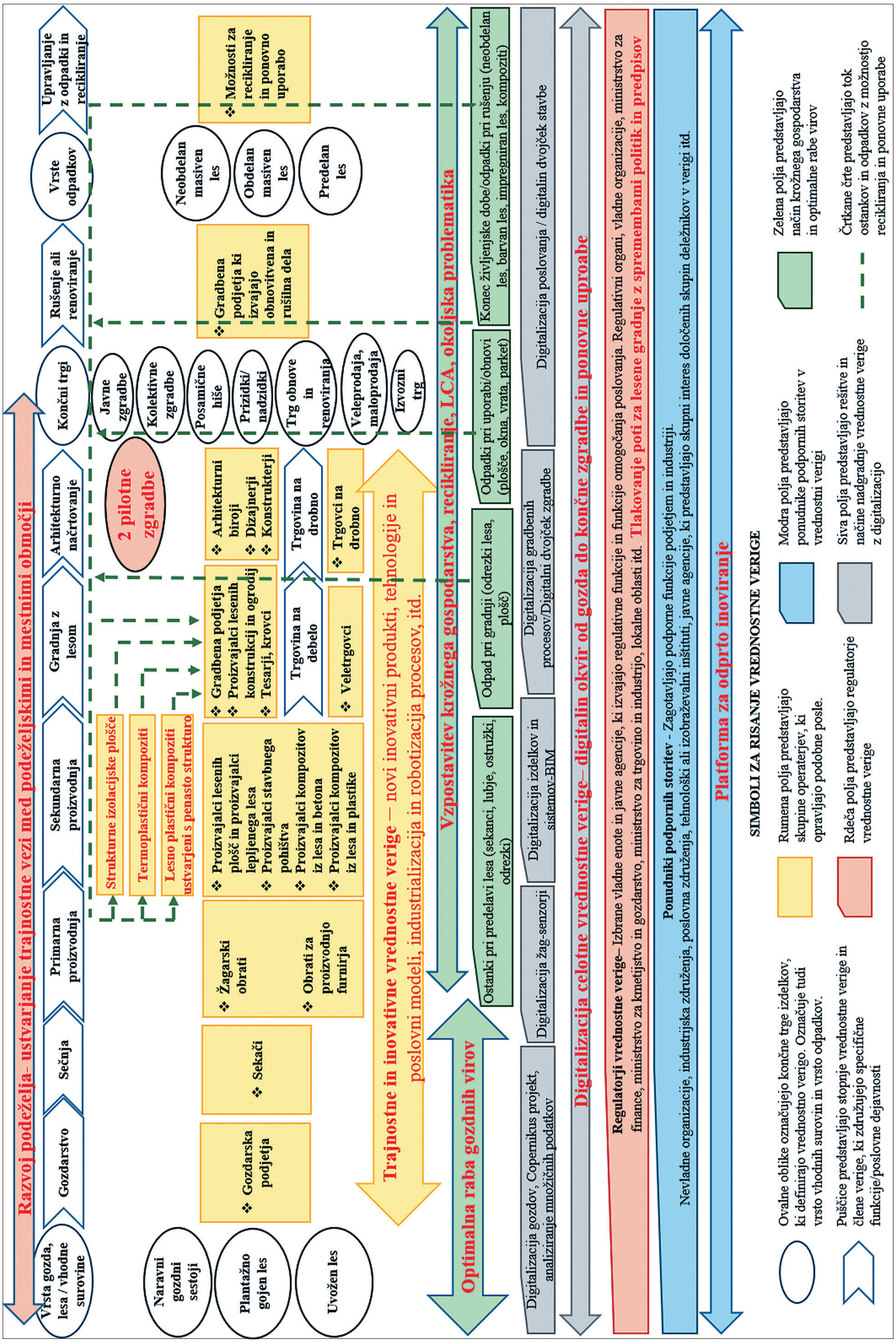
3.5 STOPNJA SODELOVANJA IN IZMENJAVE INFORMACIJ V VREDNOSTNI VERIGI
3.5 LEVEL OF COOPERATION AND INFORMATION EXCHANGE IN THE VALUE CHAIN

Zaupanje je ključnega pomena za učinkovito delovanje verig in seveda tudi za pristop k odprtemu inoviranju, ki je ključno za njeno konkurenčnost in nadaljnji razvoj. Stopnja zaupanja je težko merljiva, zato smo v ta namen preučevali raven sodelovanja in stopnjo pretoka informacij. Ugotovimo lahko, da pridobivanje in ohranjanje zaupnih odnosov predstavlja za podjetja velik izziv. Številna anketirana podjetja so izjavila, da ne zaupajo pristopu odprtega inoviranja, kjer je sodelovanje osrednjega pomena za doseganje inovacij v vrednostni verigi. Člani si izmenjujejo informacije, ideje, priložnosti, težave in celo poslovne modele. Sodelovanje je možno, če med podjetji obstaja skupna vizija, združljivi procesi, odprta komunikacija, zaupanje in predanost ter priložnosti za obojestransko korist. Verige, ki sodelujejo, lahko razvijejo izdelke in storitve, ki jih konkurenti težko posnemajo. To je eden od načinov, kako si lahko vrednostna veriga zagotovi konkurenčno prednost. Sodelovalne vrednostne verige predstavljajo najvišjo stopnjo razvoja (Springer Heinz, 2018b). S kratkoročno in na priložnosti temelječo izmenjavo partnerji vstopajo v vedno bolj raznolike odnose, vključno z medsebojno izmenjavo informacij, logističnimi dogovori, vgrajenimi storitvami in usklajenim nadzorom kakovosti. Mala in srednje velika podjetja lahko sodelujejo pri premagovanju omejitev, ki jih sama ne bi zmogla premostiti. S skupnim izvajanjem poslovnih dejavnosti in z delitvijo virov dosegajo boljšo ekonomičnost. Pogosto je sodelovanje potrebno za povečanje pogajalske moči in dostopa do trgov. Razvoj vrednostne verige zahteva rešitve pri poslovnem povezovanju. Poslovna skupnost mora uskladiti poslovne odnose, dobavo, proizvodnjo in trženje vzdolž vrednostne verige, da postane kolektivno konkurenčnejša. Uvajanje tehnoloških novosti zahteva izdatne resurse, ki so pogosto prevelik zalogaj za manjša in srednja podjetja. Poslovna partnerstva vključujejo vse več funkcij poleg zgolj nakupa in prodaje. Povezave vključujejo izmenjavo in pretok tehničnih podatkov in tehnologij ter zagotavljajo osnovo za skupne storitve (Springer Heinz, 2018b).

Anketiranci so izrazili svoje mnenje o tej temi z odgovori na odprta vprašanja:

- Dolga vrednostna veriga od sečnje lesa do gradnje povzroča nezadosten in zamuden pretok informacij pri gradbenih projektih.
- Vzpostaviti je treba usklajevanje in sodelovanje med različnimi stopnjami vrednostne verige v smeri inovacij. Trenutna stališča so konservativna in pesimistična.
- Okrepiti bi bilo treba medsebojno sodelovanje v vrednostni verigi, pa tudi mednarodno sodelovanje, da bi imeli veliko bolj evropski pristop z ustvarjanjem kritične mase in zmogljivosti za doseganje ekonomije obsega.
- Nekateri posamezni certifikati (ISO kakovost/okolje, sledljivost, itd.) niso dovolj zanesljivi, ko govorimo o zagotavljanju zadostne stopnje zaupanj. Pri ustvarjanju zaupanja še vedno vodijo osebni stiki.
- Arhitekti, projektanti, statiki, industrijski inženirji, strokovnjaki za avtomatizacijo itd. bi morali združiti moči, sodelovati in na novo oblikovati celoten proces industrializacije lesene gradnje. Potrebujemo sistem, ki mu lahko vsi v vrednostni verigi sistematično sledijo. Zdaj ni pravega sodelovanja med različnimi povezavami.
- Pri upravljanju skupne baze podatkov obstaja skrb za izkoriščanje in manipulacijo podatkov, kar lahko vodi v oškodovanje določenega člena vrednostne verige. Npr. informacije o razpoložljivosti določene vrste lesa in podatki o načrtih poseka se lahko uporabijo proti gozdarskemu členu verige, saj bi lahko druga podjetja izsiljevala nižje cene. Gre za vprašanje ravni komunikacije – kakšno raven informacij lahko zagotovite, ne da bi pri tem škodovali poslom in interesom? Kako se izogniti tržnim manipulacijam? Razpoložljive informacije in posledični vplivi na trg ne smejo nikomur škodovati ali ogroziti sodelovanja v vrednostni verigi.
- Vrednostna veriga potrebuje več informacij o razpoložljivosti, lastnostih, količini in kakovosti različnih materialov. Če podjetja dobijo zanesljive informacije, lahko začnejo razmišljati, kako te materiale uporabiti in kako povečati njihovo optimalno rabo. Prave informacije ob pravem času lahko naredijo razliko.
- Pomanjkanje tržnih informacij. Dober pregled trga je pomemben, vendar je zelo težko najti prave informacije. Na spletu je mogoče najti veliko informacij, ki pa so običajno stare že par mesecev. Vrednostne verige potrebujejo informacije o sedanjosti in informacije o obnašanju trga v prihodnosti.

Iz tega lahko povzamemo, da je za izboljšanje razmer na področju učinkovitosti preučevanih verig vrednosti najbolj potrebna izboljšava povezave med 1. in 2. stopnjo transformacije. Poleg tega si anketiranci želijo hitrejše in zanesljivejše informacije vzdolž vrednostne verige, zlasti informacije o prihodnjih potrebah trga so običajno nezanesljive in na voljo prepozno. Pretok informacij z inštituti in poslovnimi združenji je prepočasen. Podjetjem manjka zmogljivosti za hitrejšo standardizacijo in označevanje izdelkov, ti procesi zahtevajo preveč časa in stroškov. Potrebna je tudi boljša integracija malih podjetij, da dobijo več možnosti financiranja in druge podpore. Pri vzpostavitvi odprtega inoviranja je treba izboljšati zaupanje v odnosih. Stopnja sodelovanja in pretoka informacij je na zadostni ravni za osnovne poslovne odnose, potrebno pa bi bilo veliko izboljšav pri pretoku informacij in ustvarjanje zaupljivejšega okolja, da bi lahko vrednostno verigo povezali s projekti odprtega inoviranja.



Slika 9. Nadgradnja in razvoj vrednostne verige lesene gradnje.

Figure 9. Upgrading and development of the wood construction value chain.

3.6 PRILOŽNOSTI ZA NADGRADNJO IN RAZVOJ VREDNOSTNE VERIGE

3.6 UPGRADING AND DEVELOPMENT OPPORTUNITIES OF THE VALUE CHAIN

Vrednostna veriga lesene gradnje v Franciji zahteva določene ukrepe, da bo postala bolj konkurenčna in učinkovitejša. Po mnenju anketirancev so možnosti za izboljšave predvsem na področjih digitalizacije, upravljanja virov, krožnega gospodarstva, krepitev raziskovalnih in razvojnih aktivnosti ter povezovanja akterjev v verigi. Na vsakem od teh področij je v okviru projekta Basajaun predviden pester nabor rešitev za nadgradnjo vrednostne verige lesene gradnje (slika 9):

- Za rešitev pomanjkanja možnosti ponovne uporabe materialov in recikliranja po koncu uporabe proizvodov je v okviru projekta predviden razvoj treh inovativnih produktov, ki vsebujejo recikliran les. Produkti, kot so strukturne izolacijske plošče, termoplastični kompoziti in lesno-plastični kompoziti, ustvarjeni s penasto strukturo, predstavljajo krožne rešitve. Zelena polja na spodnji shemi (slika 9) predstavljajo točke, kjer nastaja odpadna surovina in tip odpadne surovine oz. materialov. Zelene črtkane črtice prikazujejo ponovno uporabo odpadne surovine v novih proizvodih in vzpostavljeno krožno gospodarstvo (slika 9). V krožnem gospodarstvu je potrebno opraviti LCA analize proizvodov in stremeti k čim manjši obremenitvi okolja. Z recikliranjem in ponovno uporabo lahko zagotovimo vhodno surovino, ki nadomesti posekan les in tako zmanjšamo vpliv na okolje. Pomembna je tudi optimalna raba gozdnih virov, vključno s sortiranjem in optimalno rabo lesa v končnih proizvodih.
- Nujne so tudi digitalne rešitve in boljši pretok informacij. Po mnenju intervjuvancev mora digitalizacija zajeti vse člene verige, vključno z upravljanjem virov, proizvodnimi procesi, distribucijo in logistiko, storitvami za stranke, strukturiranim oblikovanjem in načrtovanjem trajnostnih lesenih konstrukcij ter projektiranjem življenjskega cikla proizvodov in zgradb. Digitalizacija je potrebna po celotni vrednostni verigi, saj delna digitalizacija vodi v delne rešitve in nepopolna ujemanja med akterji. V projektu razvite digitalne rešitve vzdolž celotne vrednostne verige so prikazane v sivih poljih na shemi. Digitalni dvojniki, obdelava množičnih podatkov ter digitalizacija poslovanja in optimizacija s senzorji lahko pripomorejo k bistveno boljši učinkovitosti proizvodnih procesov, optimalni rabi virov in boljši kvaliteti končnih proizvodov. Digitalno poslovanje omogoča izboljšavo poslovnih modelov podjetij in boljše povezovanje med akterji v vrednostni verigi.
- Eden večjih izzivov za nadaljnji razvoj verige vrednosti lesene gradnje je tudi omejena razpoložljivost ustrezno usposobljene delovne sile. Za rešitev tega problema je nujno vzpostaviti platformo odprtega inoviranja, ki omogoča prenos znanja med členi v verigi in s tem zmanjša potrebo po novem kadru. Pomembna je tudi komunikacija in praktični prikaz uspešnih projektov (končni proizvodi, predstavitveni objekti ipd.), ki lahko vpliva na boljše razumevanje potenciala lesene gradnje in lokalnih vrednostnih verig. Na ta način lahko pridobimo večjo naklonjenost regionalnih avtoritet, da olajšajo in omogočijo razvoj vrednostnih verig lesene gradnje. V okviru projekta Basajaun sta to dve pilotni leseni zgradbi, ki se nahajata v Franciji in na Finskem.

4 ZAKLJUČKI

4 CONCLUSIONS

Geografski, demografski, okoljski in gospodarski kontekst Nove Akvitanije kaže na velik potencial za razvoj vrednostne verige za leseno gradnjo. Ima dobro strateško lego, veliko gozdno površino, močno regionalno gospodarstvo ter pozitiven trend migracij na obalna in urbana območja. Regija Nova Akvitanija ima zelo močan gozdno-lesni sektor in velja za eno najbolj produktivnih francoskih regij v tem sektorju. Uvrščena je med prve tri regije glede na gozdno površino, zalogo lesa in letni prirastek gozdne biomase. Regija je med vodilnimi proizvajalci izdelkov iz celuloze in papirja, plošč in žaganega lesa. Vendar pa regija zaostaja v sektorju lesene gradnje. Leta 2018 je bila Nova Akvitanija druga od trinajstih francoskih regij glede na promet v sektorju lesene gradnje (z 208 milijoni evrov prometa in 290 podjetji). Po letu 2018 se je regija soočala z zmanjševanjem dejavnosti lesene gradnje. Tako se je leta 2020 med trinajstimi regijami uvrstila šele na peto mesto (s prometom 180 milijonov evrov in

271 podjetji v leseni gradnji). Regija ima potencial, da ponovno postane ena izmed vodilnih v sektorju lesene gradnje. Ima veliko gozdov in lesnih vrst (duglazija, smreka, primorski bor in hrast), ki jih je mogoče uporabiti v proizvodih za gradnjo z visoko dodano vrednostjo. Z naraščajočim prebivalstvom in povpraševanjem po stanovanjih na obalnih območjih in v večjih urbanih središčih obstaja velik trg. Poleg tega se močno povečuje trg obnov starejših objektov, ki bo rasel tudi v prihodnje. Les je že prepoznan kot odličen trajnosten gradbeni material in številni uspešni projekti dokazujejo njegov potencial (ne samo stanovanjske stavbe, ampak tudi športne dvorane, industrijski objekti, šole itd.). Za zadovoljitev teh vse večjih potreb je treba nujno izboljšati lokalno oskrbo z žaganim lesom za gradbene proizvode in njihovo proizvodnjo. Z ustrezno podporo lokalnim lesnopredelovalnim podjetjem in gradbenim podjetjem bi lahko ta sektor dosegel visoko učinkovitost. Bistvenega pomena za dosego ciljev je razvoj proizvodnih zmogljivosti in posodobitev lesnih podjetij ter bolj učinkovit pretok informacij.

Analiza vrednostne verige lesene gradnje v Franciji je razkrila ozka grla in priložnosti za njen prihodnji razvoj. Številni akterji v tej verigi se že zavedajo prednosti in priložnosti odprtega inoviranja, digitalizacije, novih tehnologij, industrijske simbioze, skupnih storitev in inovativnih poslovnih modelov, a se po drugi strani soočajo tudi s številnimi omejitvami, ki ovirajo njen razvoj. Kljub temu da podjetja in ostali akterji v verigi prepoznavajo odprto inoviranje kot močno konkurenčno prednost, se zavedajo tudi mnogih tveganj in ovir, ki lahko vodijo v neuspešno povezovanje in nedoseganje želenih rezultatov. Stopnja zaupanja, sodelovanja in pretoka informacij trenutno ni na zadostnem nivoju za pristop k odprtemu inoviranju. Zato je še pomembnejše do podjetij pristopiti s platformo, ki jim bo olajšala sodelovanje in zagotovila koristi, ki jih lahko pridobijo z odprtim inoviranjem. Te koristi zajemajo dostop do širokega nabora znanja in sodobno opremljenih laboratorijev, hitrejše postopke certificiranja in patentiranja, lažji dostop do trga, porazdelitev stroškov razvoja, možnosti financiranja ter tržne in ostale informacije, ki bi lahko olajšale odločitve.

Priložnosti za nadaljnji razvoj vrednostih verig na področju lesene gradnje je torej veliko, kar na eni strani narekuje potrebo po usklajenih regionalnih politikah na tem področju in hkrati iskanje rešitev na nacionalni (in evropski) ravni, katere del je tudi v prispevku omenjeni projekt Basajaun. Raziskave in inovacije se morajo odzvati na posebne regionalne potrebe in zagotoviti širšo uveljavitev na trgu ter prispevati h gospodarskim učinkom v mestnih in podeželskih območjih. Koristno bi bilo izvesti podobno analizo vrednostne verige lesene gradnje v Sloveniji. Tovrstna analiza je odlično analitično orodje za ugotavljanje trenutnega stanja in potreb sektorja lesene gradnje, ter priložnosti v prihodnosti. Analiza vrednostne verige je koristna tudi za oblikovanje raznih strategij in komuniciranje sprememb z deležniki v verigi. Še posebej je koristna za spodbujanje regionalnega sodelovanja in mednarodnega poslovanja ter integracijo podjetij v širši evropski prostor.

5 POVZETEK

5 SUMMARY

Wood is increasingly recognized as a sustainable building material and climate protector. The greater use of wood as a raw material in buildings will contribute to improved performance, quality and habitability of Europe's building stock and bring many benefits for healthier and more sustainable cities. Building with wood is an emerging industry that can make a major contribution to reducing greenhouse gas emissions and promoting the development of a low-carbon circular economy. To achieve these goals, regional value chains must be brought into focus and an innovative ecosystem must be created that can generate the necessary innovative solutions. The objective of this research was to conduct an integrated analysis of the wood construction value chain in the French region of New Aquitaine. A structural analysis of the value chain was conducted.

The New Aquitaine region has a strong wood processing sector and good conditions for the use of wood in construction. The region expects an increase in the market share of wood construction in the future, although the market share of wood construction has decreased in the last three years. The region has the potential to regain a leading role in the wood construction sector. It has extensive forest resources and wood species (Douglas fir, spruce, maritime pine, and oak) that can be used

for value-added building products. With the growing population and demand for housing in coastal areas and large urban centers, there is also a large potential market. In addition, the renovation market is growing and will continue to grow in the future. To meet this growing demand, there is an urgent need to improve the local supply of lumber for building products, increase production capacity, and modernize wood processing capabilities by introducing digital solutions (more transparent and faster information flow).

The analyzed data were collected through a literature review of secondary sources and with the qualitative method of in-depth interviews. Through interviews, we analyzed the strategic competitive advantages in the chain, the barriers to market entry, the barriers to doing business, the collaboration between actors, the impact of regulations, and the management and coordination functions in the chain. We highlighted the identified barriers and opportunities for integrating open innovation processes. Fourteen in-depth interviews were conducted, and 64% of respondents saw open innovation as a strong competitive advantage, but at the same time cited several barriers, and specifically that the level of trust, collaboration and information flow in the wood construction value chain is not at a sufficient level for an open innovation approach. Company respondents indicated that the most important improvement would be the connection between the 1st and 2nd stages of transformation. In addition, they would like to see faster and more reliable information flow along the entire value chain, especially information about future market needs, which is usually unreliable and available too late. The flow of information with research institutes and business associations is also too slow. Companies lack the capacity to standardize and label products more quickly, and these processes are usually expensive and time-consuming. Small businesses also need to be better integrated so they have more opportunities for funding and other support.

We have identified opportunities to improve the value chain in the areas of digitalization, resource management, and the circular economy by strengthening research and development activities and connecting players in the chain with an open innovation platform. The desired benefits of an open innovation platform include access to a broad range of knowledge and laboratories, faster certification and patenting processes, greater access to the market, shared development costs, financing options, and faster access to market information and other information that can facilitate the decision-making process. Implementation of these solutions requires coordinated regional policies and solutions at the national (and European) level, such as in the aforementioned Basajaun European project. Research and innovation must address specific regional conditions and needs to ensure broader market adoption and contribute to economic impact in both urban and rural areas.

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OBARVANJE OLJNIH PREMAZOV Z UTEKOČINJENIM LESOM

STAINING OF OIL COATINGS WITH LIQUEFIED WOOD

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Izvleček / Abstract

Izvleček: Olja se uporabljajo za obdelavo površin lesa v notranji in zunanji uporabi. Če jim dodamo pigmente, lahko z njimi dosegamo dodatne vizualne učinke, kot so rustikalen izgled, poudarjanje lesnih por, obenem pa povečamo zaščitno sposobnost premaza proti fotodegradaciji lesne podlage. V naši raziskavi smo namesto klasičnih pigmentov uporabili naraven in obnovljiv vir, utekočinjen les (UL), ki smo ga v dve olji vmešali v dveh razmerjih. Tako pripravljene mešanice smo nanesli na vzorce bukovega in jesenovega lesa. Po nanosu smo najprej spremljali hitrost sušenja, po osušitvi pa smo določili še odpornost površin proti hladnim tekočinam ter suhi toploti. Površine smo tudi izpostavili pogojem umetnega staranja pod ultravijolično (UV) svetlobo in s tem preverili, kakšno vlogo pri tem igra dodatek UL. Barvne razlike smo določili z meritvami barve pred premazovanjem in po njem ter po izpostavitvi UV svetlobi. Naša raziskava je potrdila, da je UL kompatibilen s tungovim in Bio impregnol WM oljem, ter se posledično lahko uspešno uporablja za njuno za njuno obarvanje. Potrdili smo tudi, da dodajanje UL v tungovo olje ne vpliva na odpornost tako premazanih površin proti hladnim tekočinam in niti ne na odpornost površin obeh olj proti suhi toploti. Žal pa dodajanje UL v olja upočasnjuje hitrost sušenja. Dodatno smo tudi ugotovili, da z UL obarvani premazi niso najbolj fotostabilni.

Ključne besede: utekočinjen les, olje, premaz, obarvanje

Abstract: Oils are used to treat wood surfaces for interior and exterior use. The addition of pigments can provide additional visual effects, such as a rustic appearance that highlights the wood pores, while increasing the protective effect of the coating against photochemical decomposition of the wood substrate. In our research, instead of classical pigments we used a natural and renewable raw material, liquefied wood (LW), which we mixed in two proportions with two oils. The mixtures prepared in this way were applied to samples of beech and ash wood. After application, we first monitored the drying rate and also determined surface resistance to cold liquids and dry heat after drying. We also subjected the surfaces to artificial ageing under ultraviolet (UV) light to verify the role of the LW additive. Colour differences were determined performing colour measurements before and after coating and after exposure to UV light. Our research confirmed that LW is compatible with tung oil and Bio impregnol WM oil, and therefore can be used successfully for their staining. We also confirmed that the addition of LW to tung oil does not affect the resistance of surfaces coated in this way to cold liquids, nor the resistance of the surfaces of both oils to dry heat. Unfortunately, the addition of LW to oils slows the drying rate. In addition, we found that coatings stained with LW are not the most stable to light.

Key words: liquefied wood, oil, coating, staining

1 UVOD
1 INTRODUCTION

Obdelava lesa s premaznimi sredstvi je zelo pomembna, saj z njo površine zaščitimo pred uničujočimi dejavniki med rabo izdelka, obenem pa s površinsko obdelavo dosežemo želen končni izgled. V ta namen se uporabljajo različna premazna sredstva, ki se med sabo razlikujejo po vrsti topila, veziva, slojnosti, pigmentiranosti in še vrsti ostalih vizualnih lastnosti. Obstoječi komercialni premazi za les

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vsebujejo predvsem veziva na osnovi umetnih snovi, kar povzroča precejšen negativen vpliv na okolje. Zaradi tega poteka intenzivno iskanje ustreznih alternativ, izdelanih na osnovi obnovljivih virov. Takšna potencialna alternativa so gotovo premazi na osnovi rastlinskih olj in naravnih obnovljivih virov, ki lahko les zaščitijo pred različnimi okoljskimi dejavniki in tvorijo okolju prijazen ter učinkovit zaščitni sloj na površini lesa. Z uporabo naravnih olj lahko izboljšamo tudi vodoodbojnost lesa in njegovo dimenzijsko stabilnost. Rastlinska olja so lahko tudi zelo učinkovita pri protibakterijski in protiglivni zaščiti lesa (Teacă, 2019).

Olja delimo na sušeča, polsušeča in nesušeča. Sušeča in polsušeča olja se običajno uporabljajo za impregnacijo lesa in kot veziva v barvah in lakih. Nesušeča olja pa se učinkovito uporabljajo kot modifikatorji alkidov in kot mehčala v premazih na osnovi nitroceluloze (Teacă, 2019). V zadnjih nekaj letih se je povpraševanje po naravnih površinskih premazih močno povečalo. Zasluge za to lahko pripišemo okoljskemu ozaveščanju množične populacije. Za oznako »naravni« morajo površinski premazi izpolnjevati določene zahteve. Surovine morajo biti naravnega izvora, pridobljene iz obnovljivih virov, dovoljena je le manjša kemijska modifikacija naravnih surovin. Produkt mora biti biološko razgradljiv. Proizvodnja, uporaba in odlaganje odpadnega materiala pa ne sme negativno vplivati na okolje, proizvajalce in uporabnike.

Les po obdelavi z naravnimi premazi obdrži svojo lepoto in sčasoma dobi zanimivo patino. Če k temu dodamo še prijaznost do okolja, zlahka razumemo, zakaj se vedno več ljudi znova odloča za tradicionalne materiale za površinsko obdelavo lesa. Oljni premazi se uporabljajo za obdelavo površin lesa v notranji in zunanji uporabi. Če jim dodamo pigmente, lahko z njimi dosegamo dodatne vizualne učinke, kot so rustikalen izgled, poudarjanje lesnih por, obenem pa povečamo zaščitno sposobnost premaza proti fotodegradaciji lesne podlage. Za pigmentiranje premazov se običajno uporablja okside težkih kovin. Namesto klasičnih pigmentov pa bi lahko uporabili utekočinjen les (UL).

Poznamo več načinov izdelave UL. V osnovi gre za to, da lesno žagovino utekočinimo v reaktorju z uporabo reaktivnega topila (npr. etilen glikol, glicerol) in katalizatorja (npr. žveplove kisline). Reakcija utekočinjanja se izvaja pri segrevanju zmesi v oljni kopeli s hlajenim kondenzatorjem, pri temperaturi 180 °C, ob konstantnem mešanju, v času 90 minut. Po zaključenem postopku utekočinjanja se utekočinjeno zmes ohladi in razredči z mešanico 1,4-dioksana in destilirane vode, v razmerju 4: 1. Neutekočinjen ostanek odstranimo s filtracijo pod vakuumom (do 25 mbar) (Cheumani-Yona, 2012). Na sam proces utekočinjanja lahko vplivajo različni fizikalni in kemični dejavniki, kot so temperatura, reakcijski čas, razmerje med biomaso, reagenti in topili ter vrsta uporabljenih topil, katalizatorjev in lesne surovine. UL se lahko uporablja za izdelavo polimerov, lepil in tudi premazov (Pan et al., 2007; Demirbas, 2008; Kurimoto et al., 1999). Razvoj in analiziranje zaključnih premazov na osnovi UL torej predstavljata novost (Kumar et al., 2015). Še novejši pristop pa je raba UL za obarvanje premazov, saj tovrstnih objav nismo zasledili.

Cilj naše raziskave je bil proučiti možnost vmešanja UL v tungovo olje ter »komercialno« Bio impregnol WM olje. Ob tem smo želeli preveriti, ali dodajanje UL v oljna premaza vpliva na hitrost sušenja ter na odpornostne lastnosti tako premazanih površin. Prav tako smo želeli proučiti, ali dodajanje UL v oljna premaza poveča odpornost premazane površine proti fotodegradaciji.

2 MATERIAL IN METODE

2 MATERIAL AND METHODS

2.1 PRIPRAVA LESNIH VZORCEV

2.1 WOOD SAMPLE PREPARATION

Za pripravo vzorcev smo uporabili masiven les bukve (*Fagus sylvatica* L.) in jesena (*Fraxinus sp.*). Vzrok za izbiro prav teh lesnih vrst je bil, da imamo eno podlago difuzno poroznega lesa (bukev) in eno venčasto poroznega lesa (jesen). Bukev spada med najbolj razširjene listavce v naših gozdovih, jesen pa nam omogoča lahek nadzor nad dogajanjem na površini, saj gre za zelo svetlo lesno podlago. Poleg tega s svojo venčasto porozno strukturo omogoča zapolnjevanje por za doseganje rustikalnega izgleda.

Iz lesa obeh lesnih vrst smo pripravili radialno orientirane vzorce dveh dimenzij, in sicer večje vzorce z dimenzijami 300 mm × 150 mm × 20 mm ter manjše z dimenzijami 250 mm × 80 mm × 20 mm. Za vsako lesno vrsto smo pripravili 12 vzorcev večjih dimenzij in šest vzorcev manjših dimenzij ter dva manjša vzorca za kontrolo, ki ju nismo premazali. Vzorce smo nažagali, poskobljali in jih pred samim nanosom olja dobro zbrusili z brusnim papirjem granulacije 180. Večje vzorce smo nato uporabili za preizkušanje odpornosti proti hladnim tekočinam ter suhi toploti, manjše vzorce pa za preizkušanje fotostabilnosti.

2.2 PREMAZNA SREDSTVA
2.2 COATING MATERIALS

V naši raziskavi smo za obarvanje z utekočinjenim lesom (UL) uporabili dva oljna premaza, tungovo olje ter sredstvo Bioimpregnol WM, oba proizvajalca Helios TBLUS d.o.o., član skupine KANSAI HELIOS (Količevo, Slovenija).

Tungovo olje je pridobljeno s stiskanjem semen iz oreščkov tungovega drevesa (*Vernicia fordii*). Je razmeroma poceni in okolju prijazno, ob stiku z zrakom se posuši in tvori prozoren sloj. Tungovo olje se je doslej izkazalo za eno najučinkovitejših olj za zaščito lesa. Vendar, tako kot druga olja zaradi visoke viskoznosti ne prodre globoko v les. Premaz iz tungovega olja naj bi se uporabljal tudi za površine, ki so izpostavljene morski vodi in v visokogorskih klimatskih pogojih (Sam, 2020).

Bio impregnol WM (v nadaljevanju bioimpregnol olje) je impregnacijsko sredstvo na osnovi naravnih rastlinskih olj in mineralnega medicinskega olja. Primerno je za zaščito notranjega lesenega pohištva, kot so lesene omare, mize, postelje. Ima tudi certifikat SIST EN 71-3 (2013) za varnost otroških igrač, zato je primeren tudi za zaščito otroškega pohištva. Kot navaja proizvajalec, je pomembno, da površino, obdelano z oljem, redno vzdržujemo in tako podaljšamo njeno življenjsko dobo (Helios, 2017).

2.3 UTEKOČINJEN LES
2.3 LIQUEFIED WOOD

V raziskavi uporabljen UL je bil pridobljen iz lesa pajesena (*Ailanthus altissima* (Mill.) Swingle). Kot topilo v procesu utekočinjenja je bil uporabljen etilen glikol $(CH_2OH)_2$, kot katalizator pa žveplova (VI) kislina (H_2SO_4). Natančen opis postopka priprave UL je opisan v raziskavi Merela in sodelavci (2019). Delež suhe snovi v UL je znašal 35,7 %, izmerjena viskoznost UL z Brookfieldovim viskozimetrom (model DV-II+ Pro) pri izbranem vretenu št. 7, hitrosti 100 obratov vretena na minuto in obremenitvi osi 45,9 %, pa je bila 4570 mPas.

2.4 PRIPRAVA PREMAZOV IN NANAŠANJE
2.4 COATING PREPARATION AND APPLICATION

Olji smo v UL z magnetnim mešalom zmešali v dveh masnih razmerjih, in sicer olje: UL = 10: 1 in olje: UL = 10: 2. Vzorce iz lesa jesena in bukve smo izdatno premazali ročno z gobico, počakali nekaj minut in nato odvečno količino obrisali s suho gobico. Nanos smo vseskozi spremljali s tehtanjem. Povprečna količina prvega nanosa vseh pripravkov skupaj je znašala 27,2 g/m². Naslednji dan je sledil še drugi nanos premaznih sredstev, ki je povprečno znašal 12,8 g/m², kar je bilo pričakovano, saj se sredstva zaradi predhodnega nanosa niso več tako vpijala v podlago.

2.5 MERJENJE BARVE IN IZRAČUN BARVNIH RAZLIK
2.5 COLOUR MEASUREMENT AND CALCULATION OF COLOUR DIFFERENCES

Za numerično vrednotenje barve smo uporabili spektrofotometer SP62, proizvajalca X-Rite GmbH–OPTRONIK (Planegg, Nemčija). Pri tem smo uporabili standardizirano svetlobo D65 in vključeno zrcalno komponento (*SPIN–specular component included*) (Pavlič et al., 2008). Za merjenje barve smo izbrali CIELAB sistem, ki je najpogosteje uporabljen in izpopolnjen sistem za numerično vrednotenje barve. Predstavlja matematično kombinacijo kartezijskega in cilindričnega koordinatnega sistema (Golob & Golob, 2001), barva pa je opredeljena s tremi osnovnimi vrednostmi:

- L^* – določa svetlost barve in zavzema vrednost od 0 (absolutno črno) do 100 (absolutno belo),
- a^* – določa lego barve na rdeče (+)–zeleni (–) osi,
- b^* – določa lego barve na rumeno (+)–modri (–) osi.

Po CIELAB sistemu barvne razlike izrazimo z vrednostjo ΔE*, ki jo izračunamo po naslednji enačbi (1):

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (1)$$

kjer je:

ΔL^* … razlika med barvno komponento svetlosti barve L^*,

Δa^* … razlika med barvno komponento a^* in

Δb^* … razlika med barvno komponento b^*.

Na vsakem vzorcu smo opravili po 10 meritev barve pred premazovanjem in po njem ter po izpostavitvi UV žarkom. Vsaka meritev je bila opravljena na različnem mestu. S tem smo pridobili kar se da objektivne rezultate. Za lažjo vizualno predstavo površin vzorcev smo le-te dodatno še optično prebrali, za kar smo uporabili optični bralnik Mustek S 2400 Plus A3 (Mustek Europe B.V., Nizozemska) (ločljivost 600 pik na palec, barvna globina 24 bitov).

2.6 PROUČEVANJE HITROSTI SUŠENJA
2.6 DRYING TIME MONITORING

Hitrost sušenja premaznih sistemov smo začeli spremljati tretji dan po zadnjem, drugem nanosu premazov. Spremljali smo jo en teden vsak dan, nato pa v razmaku enega tedna do končne suhosti. Za to smo uporabili metodo z obteževanjem po standardu DIN 53 150 (2007), ki smo jo prilagodili tako, da smo določali samo zadnjo stopnjo suhosti (7) z največjo obremenitvijo površine. Za preizkus smo potrebovali napravo za obteževanje (Drying Time Tester Model 415, ERICHSEN GmbH & Co. KG, Hemer, Nemčija), list papirja formata A4 ter premazan vzorec večjih dimenzij. List papirja smo položili na premazano površino in ga obremenili z gumijastim diskom premera 20 mm in pritisno silo 200 N za 60 s (slika 1). Premazni sistem je bil posušen, ko pri tovrstnem obremenjevanju na sprednji in zadnji strani lista ni bilo več vidnih sledi premaza, prav tako pa na površini ni bilo zaznati nobenih sprememb.

Slika 1. Določanje hitrosti sušenja.
Figure 1. Drying time determination.

2.7 DOLOČANJE ODPORNOSTNIH LASTNOSTI POVRŠINE
2.7 DETERMINATION OF SURFACE RESISTANCE PROPERTIES

2.7.1 Odpornost proti hladnim tekočinam
2.7.1 Resistance to cold liquids

Odpornost površin proti hladnim tekočinam smo določali po metodi SIST EN 12720 (2014). Pri tem smo uporabili naslednje tekočine in čase izpostavitve: kava–10 min, 1 h, 6 h; voda–1 h, 6 h; aceton–2 min, 10 min; znoj (kislinski)–1 h; znoj (bazični)–1 h; čistilno sredstvo–6 h, alkohol (48 % raztopina etanola)–1 h; rdeče vino (refošk, proizvajalec Vinakoper iz Kopra)–1 h. Kislinski in bazični znoj ter čistilno sredstvo smo pripravili po navodilih standarda SIST EN 12720 (2014).

Postopek preskušanja je potekal tako, da smo papirnat tampon gramature 480 g/m^2 najprej za 30 s namočili v izbrano preizkusno tekočino, nato položili na vzorec in pokrili s stekleno čašo. Po predvidenem pretečenem času izpostavitve smo tampon odstranili. Ocenjevanje je potekalo 16 h po zaključeni izpostavitvi. Pred ocenjevanjem smo vzorce očistili s predpisano raztopino čistilnega sredstva. Površino smo ocenjevali s številčnimi vrednostmi, in sicer po številčni lestvici od 5 (najboljša ocena) do 1 (najslabša ocena) (SIST EN 12720 (2014)).

2.7.2 Odpornost proti suhi toploti
2.7.2 Resistance to dry heat

Odpornost površine proti suhi toploti smo določali po standardu SIST EN 12722 (2009). Standardizirane aluminijaste diske smo segreli v sušilniku na 60 °C in jih za 20 min izpostavili na površini. Ocenjevanje je potekalo 16 ur po zaključeni obremenitvi. Površino smo zopet ocenjevali s številčnimi vrednostmi, in sicer po številčni lestvici od 5 (najboljša ocena) do 1 (najslabša ocena) (SIST EN 12722 (2009)).

2.8 IZPOSTAVITEV VZORCEV
2.8 SAMPLE EXPOSURE

Da bi preverili fotostabilnost površin, premazanih z obarvanimi oljnimi pripravki, smo vzorce izpostavili za 7 dni v UV komori za umetno pospešeno staranje brez kondenzacije ali vodnega pršenja. Izpostavitev smo izvedli s klasično UV žarnico z žarilno nitko ULTRA VITALUX 300 W (Osram, 2021), ki poleg vidne svetlobe seva tudi z UV svetlobo valovne dolžine od 315 nm do 400 nm (UVA; 13,6 W) in od 280 nm do 315 nm (UVB; 3,0 W). Po izpostavljenosti smo preizkušance odstranili iz komore in jih pred merjenjem barve 24 ur klimatizirali pri sobni temperaturi (20 ± 2 °C).

3 REZULTATI IN RAZPRAVA
3 RESULTS AND DISCUSSION

Za lažje označevanje rezultatov smo v preglednicah in slikah uporabili oznake, in sicer: tungovo olje (T), bioimpregnol olje (B), bukovina (b), jesenovina (j) ter mešalno razmerje (X: UL=10: X).

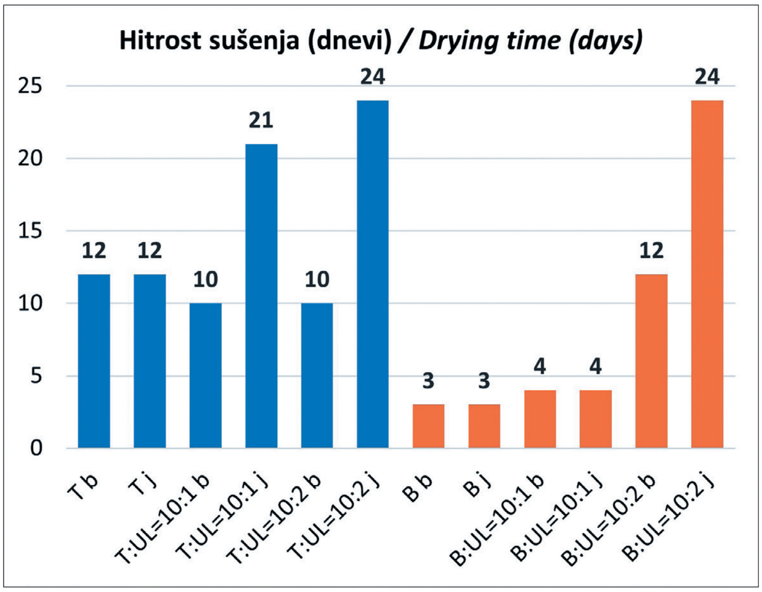
3.1 HITROST SUŠENJA
3.1 DRYING TIME

Hitrost sušenja premaznih sistemov smo spremljali, da bi ugotovili, kako na sušenje premaza vpliva lesna vrsta, uporabljeno olje ter dodatek UL.

Iz slike 2 je razvidno, da se je bioimpregnol olje (oranžni stolpci) utrjevalo in se sušilo hitreje kot tungovo olje (modri stolpci). Podlagi, premazani le z bioimpregnol oljem, sta se sušili 3 dni, podlagi, premazani s premazom, zmešanim z UL, v razmerju B: UL=10: 1, pa 4 dni. Bukov vzorec, premazan s premazom B: UL=10: 2, 12 dni in jesenov vzorec 24 dni.

Če pogledamo še tungovo olje, opazimo, da je prišlo do večjih razlik v času utrjevanja. Predvidevamo lahko, da je do odstopanj prišlo tudi zaradi različne količine nanosa premazov. Najkrajši čas sušenja sta potrebovala bukova vzorca, premazana z mešanico tungovega olja in UL v razmerju T: UL=10: 1 in T: UL=10: 2, in sicer 10 dni. Sledita jesen in bukev, premazana s čistim tungovim oljem (12 dni) ter jesen, premazan s T: UL=10: 2 (21 dni). Najdlje se je sušil jesenov vzorec, premazan s T: UL=10: 2.

Iz dobljenih podatkov o času sušenja lahko sklepamo, da dodatek UL upočasni sušenje premaznega sistema. Na počasnejše sušenje z UL pripravljenih mešanic bi lahko vplivale slabo hlapne komponente iz UL, kot je npr. etilen glikol, glicerol. Zelo verjetno UL tudi otežuje dostop kisika iz zraka, ki promovira sušenje olj. Velja pa še omeniti, da tudi že sam UL zelo počasi utrjuje. Budija (2010) je v svoji raziskavi ugotovil, da utekočinjen topolov les v glicerolu za 98 % stopnjo zamreženja pri 130 °C potrebuje kar 7 dni. Kakšen bi bil ta čas utrjevanja pri sobnih pogojih, pri katerih so se sušili naši sistemi, pa ni znano. Poleg tega pa na sušenje vplivajo tudi lastnosti premazane podlage. Tako lahko opazimo počasnejše sušenje premaznih sredstev na jesenovi podlagi (slika 2, b in j). Pri bukovem lesu so pore sicer manjše (tangencialni premer trahej okoli 100 µm), a le-teh je veliko in so dokaj enakomerno (difuzno) razporejene (Čufar, 2016). Zaradi tega so



Slika 2. Hitrost sušenja (T – tungovo in B – bioimpregnol olje, UL – utekočinjen les, b – bukovina, j – jesenovina, 10: 1 ali 10: 2 – mešalno razmerje).

Figure 2. Drying time (T – tung and B – bioimpregnol oil, UL – liquefied wood, b – beech wood, j – ash wood, 10:1 ali 10:2 – mixing ratio).

se uporabljena premazna sredstva hitreje in globlje vpijala, kar je ob enakem nanosu kot pri jesenovem lesu rezultiralo v manjši količini sredstva na površini lesa, ki se je tako lahko hitreje sušilo. Jesenov les pa je venčasto porozen, sicer ima premer trahej nad 200 µm, a teh je dosti manj kot pri bukovem lesu in so razporejene predvsem v ranem lesu. Osnovno tkivo pa je sestavljeno predvsem iz debelostenih vlaken (Čufar, 2006), ki so slabo vpijala premazna sredstva.

3.2 ODPORNOSTNE LASTNOSTI POVRŠINE
3.2 SURFACE RESISTANCE PROPERTIES

Pri določanju odpornosti površin proti suhi toploti pri temperaturi 60 °C na nobeni površini preskušenih vzorcev nismo zaznali sledi poškodb oz. sprememb (ocena 5). Ocenimo lahko, da so vsi uporabljeni sistemi relativno dobro odporni proti suhi toploti.

Po izpostavljenosti hladnim tekočinam smo sprva poškodbe ocenili pri sobni svetlobi, nato pa še v kabinetu za opazovanje poškodb. Kot rezultat smo vedno navedli najnižjo oceno, ki smo jo zaznali pri omenjenem načinu opazovanja. Ocene odpornosti so podane v preglednici 1. Za večjo preglednost smo celice ocen obarvali z zeleno-rumeno barvno lestvico, kjer zelenkast odtenek predstavlja najboljše ocene, rumenkast pa najslabše.

Vidimo lahko, da so sistemi s tungovim oljem na splošno odpornejši proti hladnim tekočinam kot sistemi z bioimpregnol oljem. Videti je tudi, da dodajanje UL v tungovo olje ne zmanjša odpornosti premaznega sistema proti hladnim tekočinam, medtem ko je to pri bioimpregnol olju nekoliko drugače, saj sta se sistema z največjim dodatkom UL (10: 2) izkazala za slabše odporna proti čistilnemu sredstvu, acetonu in etanolu. Predvidevamo lahko le, da je ta slabša odpornost proti omenjenim tekočinam posledica manjše stopnje polimerizacije sušečega se olja zaradi večjega dodatka UL, ki je oteževal za utrjevanje potreben dostop kisika iz zraka. Do izpiranja UL iz utrjenega filma, ki bi tudi lahko

Preglednica 1. Odpornost površinskih sistemov proti hladnim tekočinam (T – tungovo in B – bioimpregnol olje, UL – utekočinjen les, b – bukovina, j – jesenovina, 10: 1 ali 10: 2 – mešalno razmerje).

Table 1. Resistance of surface systems to cold liquids (T – tung and B – bioimpregnol oil, UL – liquefied wood, b – beech wood, j – ash wood, 10:1 ali 10:2 – mixing ratio).

Tekočina / Liquid	Izpostavitev / Exposure	T b	T j	T:UL=10:1 b	T:UL=10:1 j	T:UL=10:2 b	T:UL=10:2 j	B b	B j	B:UL=10:1 b	B:UL=10:1 j	B:UL=10:2 b	B:UL=10:2 j
Voda / Water	6 h	4	5	5	5	5	5	5	4	5	4	4	4
	1 h	5	5	5	5	5	5	5	5	5	5	5	5
Čistilno sredstvo / Cleaning agent	6 h	4	5	4	5	5	5	5	5	5	5	5	3
Kava / Coffe	6 h	4	5	5	5	5	5	5	4	5	5	5	4
	1 h	5	5	5	5	5	5	5	5	5	5	5	5
	10 min	5	5	5	5	5	5	5	4	5	5	5	5
Aceton / Acetone	2 min	5	5	5	5	5	5	5	5	5	5	5	5
	10 min	5	5	5	5	5	5	5	5	4	5	3	3
Znoj-kislina / Perspiration-acid	1 h	5	5	5	5	5	5	5	5	5	4	5	5
Znoj-baza / Perspiration-basic	1 h	4	5	5	5	5	5	5	5	5	5	5	5
Etanol (48 %) / Ethanol (48 %)	1 h	4	5	4	5	5	5	5	5	5	5	3	3
Vino / Vine	1 h	4	5	5	5	5	5	5	4	5	5	5	5

rezultiralo v slabši odpornosti proti tekočinam, pa ni prišlo, saj so bili papirnati tamponi po izpostavitvi čisti/nekontaminirani.

Določanje odpornosti proti hladnim tekočinam je izrednega pomena, saj nam omogoča, da glede na dobljene rezultate preizkušenih vzorcev določimo namen, za katerega se lahko premaz oz. premazana površina uporablja.

Z izjemo B: UL=10: 2 so ostali preskušeni sistemi dobro odporni proti suhi temperaturi in hladnim tekočinam, saj so njihove odpornostne lastnosti boljše od sistemov, ki sta jih v svoji raziskavi proučevala Pogorelčnik (2017) (laneno, orehovo, konopljino, kokosovo, decking in tungovo olje) in Bence (2013) (laneno, tungovo, konopljino, parafinsko in olje za les v stiku z živili, premaz na osnovi sončničnega, sojinega in osatovega olja, laneni firnež, voščena lazura, čebelji vosek in še dve mešanici okolju prijaznih sredstev). Prav tako so naši rezultati boljši od rezultatov iz literature, kot jih navajata Petrič (2002a; b) ter Mihevc in sodelavci (1994), ki ugotavljata, da imajo oljene in voskane površine v splošnem slabšo odpornost proti tekočinam.

3.3 SPREMEMBA BARVE PO PREMAZOVANJU IN PO IZPOSTAVITVI
3.3 COLOUR CHANGE AFTER COATING AND AFTER EXPOSURE

Spremembe barve, ki so se zgodile zaradi premazovanja vzorcev, so prikazane v preglednici 2. Iz vrednosti sprememb posameznih barvnih komponent *ΔL**, *Δa** in *Δb** je razvidno, da so vsi vzorci po premazovanju potemneli, pordečeli in porumeneli. Najmanjšo barvno razliko *ΔE** opazimo pri vzorcih, premazanih z bioimpregnol oljem (B b, B j), največjo pa pri jesenovem vzorcu, premazanem s premazom B: UL=10: 2. Videti je torej, da bioimpregnol olje povzroča manjše barvne spremembe kot tungovo olje. Olja v kombinaciji z UL povzročajo večje spremembe kot čista olja, kar je seveda posledica temnejše mešanice olj in UL, ki je v tekoči fazi temno rjavo obarvan. Večje spremembe v barvi so se po premazovanju zgodile na podlagi iz jesenovega lesa. Sklepamo, da je to posledica začetne svetlejše barve samega jesenovega lesa.

V preglednici 3 primerjamo barvo vzorcev pred in po 7-dnevni izpostavitvi UV svetlobi. Opazimo, da rezultati predvsem pri vrednosti *ΔL** precej variirajo. Večina vzorcev je posvetlila in porumenela, vzorci so postali malenkost bolj rdečkasti. Razberemo lahko, da so potemneli le vzorci, premazani s čistim tungovim in bioimpregnol oljem. Najmanjšo razliko v barvi *ΔE** so imeli bukovi vzorci, premazani s tungovim oljem v razmerju T: UL=10: 1 in T: UL=10: 2 in s čistim tungovim oljem. Največje barvne razlike *ΔE** pa so se pojavile na jesenovih vzorcih, premazanih z bioimpregnol oljem in v primeru njegove kombinacije z UL.

Iz dobljenih rezultatov lahko sklepamo, da je za barvne spremembe, povzročene zaradi UV žarkov, bolj dovzetno bioimpregnol olje. Dodajanje UL v oljna premaza bistveno ne izboljša odpornosti premaznih sistemov proti barvnim spremembam. Zanimivo je tudi, da so barvne spremembe premazanih bukovih vzorcev s čistim tungovim in bioimpregnol ojem ter njunih mešanic z UL vseeno manjše kot so barvne spremembe nepremazanih bukovih vzorcev (preglednica 3, ΔE^*_b = 10,5), medtem ko to za jesenove vzorce ne velja.

Preglednica 2: Sprememba barvnih komponent pred premazovanjem in po njem (ΔL*, Δa* in Δb*) ter izračunana sprememba barve *(ΔE*)* (T – tungovo in B – bioimpregnol olje, UL – utekočinjen les, b – bukovina, j – jesenovina, 10: 1 ali 10: 2 – mešalno razmerje).

Table 2. Difference of colour components before and after exposure (ΔL*, Δa* in Δb*) and calculated colour difference (ΔE*) (T – tung and B – bioimpregnol oil, UL – liquefied wood, b – beech wood, j – ash wood, 10:1 ali 10:2 – mixing ratio).

Sistem / System	ΔL*	Δa*	Δb*	ΔE*
T b	–11,1	5,7	10,5	16,3
T j	–3,9	1,9	10,6	11,5
T:UL=10:1 b	–16,9	3,6	5,2	18,0
T:UL=10:1 j	–14,9	4,0	9,5	18,1
T:UL=10:2 b	–13,0	4,5	7,9	15,8
T:UL=10:2 j	–15,2	3,5	7,2	17,2
B b	–5,6	2,2	5,4	8,1
B j	–2,2	0,7	3,0	3,8
B:UL=10:1 b	–15,0	2,6	3,9	15,7
B:UL=10:1 j	–21,8	5,2	2,5	22,6
B:UL=10:2 b	–16,1	2,8	3,8	16,8
B:UL=10:2 j	–30,5	4,9	3,0	31,0

Preglednica 3. Sprememba barvnih komponent (ΔL*, Δa* in Δb*) in izračunana sprememba barve po izpostavitvi (ΔE*) (T – tungovo in B – bioimpregnol olje, UL – utekočinjen les, b – bukovina, j – jesenovina, 10: 1 ali 10: 2 – mešalno razmerje).

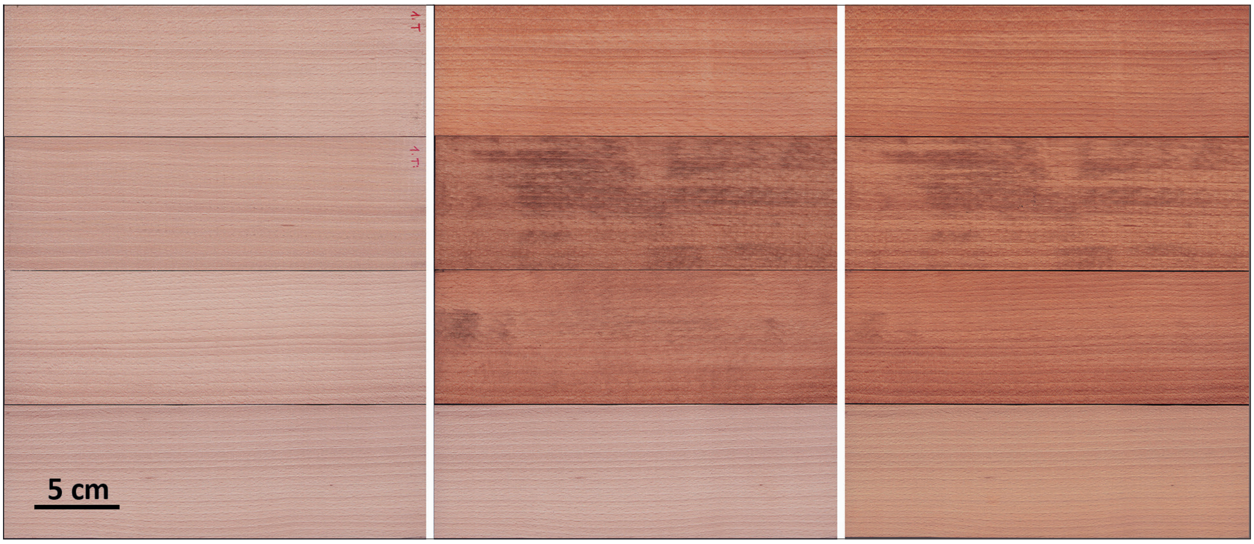
Table 3. Difference of colour components (ΔL*, Δa* in Δb*) and calculated colour difference after exposure (ΔE*) (T – tung and B – bioimpregnol oil, UL – liquefied wood, b – beech wood, j – ash wood, 10:1 ali 10:2 – mixing ratio).

Sistem / System	ΔL*	Δa*	Δb*	ΔE*
T b	–3,6	1,3	2,8	4,8
T j	–7,0	4,3	9,5	12,6
T:UL=10:1 b	1,9	1,2	3,4	4,1
T:UL=10:1 j	0,6	2,5	7,1	7,6
T:UL=10:2 b	–0,8	1,6	3,9	4,3
T:UL=10:2 j	1,2	1,9	7,7	8,1
B b	–4,9	2,5	7,4	9,2
B j	–6,5	4,0	13,8	15,8
B:UL=10:1 b	4,5	1,0	5,0	6,8
B:UL=10:1 j	8,9	–1,5	8,9	12,7
B:UL=10:2 b	4,6	1,1	5,2	7,0
B:UL=10:2 j	13,8	–0,2	7,5	15,7
b	–4,6	1,8	9,1	10,5
j	–5,7	2,9	11,6	13,2

3.3.1 Primerjava optično prebranih vzorcev
3.3.1 Scanned sample comparison

Vzorce smo optično prebrali pred premazovanjem in po njem ter po izpostavitvi UV svetlobi. Namen tega je bil vizualizirati spremembe, ki so se zgodile na vzorcih po posameznem koraku. Vzorce smo vedno optično prebrali po enakem zaporedju. Od spodaj navzgor se najprej nahaja kontrolni nepremazani vzorec navedene lesne vrste, nato vzorec, premazan z omenjenim oljem v razmerju 10: 2, nato vzorec, premazan v razmerju 10: 1, čisto zgoraj pa se nahaja vzorec, premazan s čistim oljem (slike od 3 do 6). Vse prej navedene razlike barvnih komponent in izračunane spremembe barve po premazovanju ter po izpostavitvi se lepo vidijo iz slik optično prebranih vzorcev in se vizualno ujemajo z rezultati iz preglednic 2 in 3.

S primerjavo slik vzorcev opazimo, da je pri oljih, ki so zmešana v kombinaciji z UL, prišlo do močnejšega obarvanja. To je predvsem vidno na vzorcih iz jesenovega lesa, saj gre v osnovi za svetel les (sliki 5 in 6). Največjo razliko v barvi po premazovanju lahko opazimo pri premazih, mešanih v razmerju 10: 2, kar je pravzaprav pričakovano, saj je stopnja obarvanja višja. Pri vzorcih, ki so bili obsevani z UV svetlobo, pa lahko ugotovimo, da z UL obarvani vzorci niso najbolj fotostabilni. Jasno razvidno je, da so ti vzorci po izpostavitvi močno obledeli in izgubili temno barvo, ki jo je dajal UL, zmešan



Slika 3. Bukovi vzorci pred (levo) premazovanjem s tungovim oljem in po njem (v sredini) ter po UV izpostavitvi (desno).

Figure 3. Beach samples before (left) and after coating with tung oil (in the middle) and after UV exposure (right).

s premaznim oljem. To se še najbolj opazi pri jesenovih vzorcih, premazanih z bioimpregnol oljem, so pa ti vzorci po izpostavitvi UV svetlobi kljub temu ohranili rustikalen izgled, temnejše obarvane pore (slika 6)

4 SKLEPI
4 CONCLUSIONS

Rezultati naše raziskave so pokazali, da se je najhitreje sušilo čisto bioimpregnol olje, ki je za osušitev potrebovalo 3 dni, ter bioimpregnol olje v kombinaciji z UL (B: UL=10: 1), ki je za utrjevanje potrebovalo 4 dni. Najdlje sta za utrjevanje potrebovala sistema T: UL=10: 2 in B: UL=10: 2 na jesenovi podlagi, in sicer 24 dni. Sklepamo lahko, da je

Slika 4. Bukovi vzorci pred (levo) premazovanjem z bioimpregnol oljem in po njem (v sredini) ter po UV izpostavitvi (desno).
Figure 4. Beach samples before (left) and after coating with bioimpregnol oil (in the middle) and after UV exposure (right).

Slika 5. Jesenovi vzorci pred (levo) premazovanjem s tungovim oljem in po njem (v sredini) ter po UV izpostavitvi (desno).
Figure 5. Ash samples before (left) and after coating with tung oil (in the middle) and after UV exposure (right).

Slika 6. Jesenovi vzorci pred (levo) premazovanjem z bioimpregnol oljem in po njem (v sredini) ter po UV izpostavitvi (desno).
Figure 6. Ash samples before (left) and after coating with bioimpregnol oil (in the middle) and after UV exposure (right).

bioimpregnol olje hitreje sušeče kot tungovo olje. Bolj kot olja obarvamo z UL, počasnejše bo utrjevanje premaza.

Če primerjamo spremembo barve pred premazovanjem in po njem, opazimo, da je do največje spremembe prišlo na jesenovi podlagi, premazani z bioimpregnol oljem v kombinaciji z UL. Vzrok za takšne rezultate lahko pripišemo temneje obarvanemu UL ter jesenovi podlagi, ki je zelo svetla. Do najmanjših barvnih sprememb je prišlo na podlagah, premazanih samo z bioimpregnol oljem. Pri barvni spremembi vzorcev po izpostavitvi UV svetlobi je do največje barvne spremembe prišlo pri vzorcih, premazanih s čistim bioimpregnol oljem in bioimpregnol oljem v kombinaciji z UL. Rezultati nakazujejo, da je bioimpregnol olje mnogo bolj foto nestabilno kot tungovo olje.

Najboljšo odpornost proti hladnim tekočinam ima premaz T: UL=10: 2. Na obeh podlagah, premazanih s tem premazom, namreč ni bilo vidnih nobenih poškodb. Sklepamo lahko, da je tungovo olje v primerjavi z bioimpregnol oljem odpornejše proti hladnim tekočinam. Pri izpostavljenosti suhi toploti pri 60 °C ni prišlo do vidnih napak na nobeni podlagi. Trdimo lahko, da so vsa olja in z UL mešana olja odporna na vpliv suhe toplote.

Vsako olje ima drugačne lastnosti, druge prednosti in slabosti. Uporaba posameznega olja oziroma olja v kombinaciji z UL je predvsem odvisna od potreb in mesta uporabe površine. Naša raziskava je potrdila, da je UL kompatibilen s tungovim in bioimpregnol oljem, ter se posledično tako lahko uporablja za obarvanje le-teh. Potrdili smo tudi, da dodajanje UL v tungovo olje ne vpliva na odpornost tako premazanih površin proti hladnim tekočinam. Žal pa dodajanje UL v olja upočasnjuje hitrost sušenja. Dodatno smo tudi ugotovili, da z UL obarvani premazi niso najbolj fotostabilni. Zaradi tega bi bilo zanimivo izvesti primerjalno raziskavo z uporabo industrijskih pigmentnih past, da bi dejansko lahko potrdili ali ovrgli to domnevo.

5 POVZETEK
5 SUMMARY

In our research, we investigated the possibility of mixing liquefied wood (LW) with tung oil and commercially available Bio impregnol WM oil (hereinafter referred to as bioimpregnol oil). At the same time, we wanted to test whether the addition of LW to oil coatings affects the drying speed and the resistance properties of surfaces coated in this way. We also wanted to investigate whether the addition of LW to oil coatings increases the resistance of the coated surface to photodegradation.

Solid beech (*Fagus sylvatica* L.) and ash (*Fraxinus sp.*) woods were used to produce the samples. The LW used for the study was obtained from wood of the tree of heaven (*Ailanthus altissima* (Mill.) Swingle). During liquefaction, ethylene glycol was used as a solvent and sulphuric acid as a catalyst. The oils were mixed with LW using a magnetic stirrer in two mass ratios, namely oil: LW = 10: 1 and oil: LW = 10: 2. The ash and beech wood samples were coated by hand with a sponge. The application was carried out in the outlet, waiting a few minutes and then wiping off the excess amount with a dry sponge. After application the drying speed was first monitored, and after drying the resistance of the surfaces to cold liquids and dry heat was determined. We also subjected the surfaces to artificial ageing under ultraviolet (UV) light to determine the role of the LW additive. The colour differences were determined using colour measurements before and after coating and after exposure to UV light.

The results of our tests showed that pure bioimpregnol oil dried the fastest, while oil mixtures with the highest LW additive, in a ratio of 10:2, dried the longest. The more we stained the oils with LW, the slower the coating cured. The greatest colour change after coating occurred with the ash base coated with bioimpregnol oil in combination with LW. The reason for these results lies in the dark colour of the LW and the very light colour of the ash wood. The least colour changes occurred with substrates that were only coated with bioimpregnol oil. After irradiation with UV light, the greatest colour changes occurred in samples coated with pure bioimpregnol oil and bioimpregnol oil in combination with LW. The results indicate that bioimpregnol oil is significantly less resistant to light than tung oil. The resistance of the surfaces of all coating systems used to cold liquids was very good, although tung oil was found to be even more resistant than bioimpregnol oil. We can also state that all oils and oils mixed with LW are resistant to the influence of dry heat.

Our research confirmed that LW is compatible with tung oil and bioimpregnol oil and can be therefore used for their staining. We have also confirmed that the addition of LW to tung oil does not affect the resistance of such coated surfaces to cold liquids. Unfortunately, the addition of LW to oils slows down the drying speed. We have also found that coatings stained with LW are not the most light stable.

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VARIABILITY OF THE CHEMICAL COMPOSITION OF THE WOOD AND BARK OF TWO TROPICAL HARDWOODS FROM GHANA

VARIABILNOST KEMIČNE SESTAVE LESA IN SKORJE DVEH TROPSKIH LISTNATIH DREVESNIH VRST IZ GANE

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Abstract / Izvleček

Abstract: The study aims to investigate the chemical properties of the wood and bark of two tropical tree species *Nesogordonia papaverifera* and *Holarrhena floribunda* from Ghana to increase the efficiency of their utilization. For this purpose, for each of the species five mature trees with similar diameters at breast height were selected. Lignin, cellulose, hemicellulose, and total extractive content were determined from the sapwood and heartwood and bark of stems and branches of both species. The tests were conducted using the Technical Association of the Pulp and Paper Industry (TAPPI) standards. The lignin, cellulose, hemicellulose, and total extractive content vary along different locations in the stems and branches in both species. The sapwood generally had higher cellulose and hemicellulose content, while the heartwood and bark had a greater amount of lignin and extractives. This may affect the lower durability of sapwood. This study shows that heartwood of both *Nesogordonia papaverifera* and *Holarrhena floribunda* can be considered a source of value-added compounds.

Keywords: structural components, total extractives, stem/branch wood, bark, *Nesogordonia papaverifera, Holarrhena floribunda*

Izvleček: Raziskana je bila kemi*čna* zgradba lesa in skorje dveh tropskih listavcev, *Nesogordonia papaverifera* in *Holarrhena floribunda* iz Gane za izboljšanje uporabe. V ta namen je bilo za raziskave izbranih pet odraslih dreves vsake vrste. Debla so imela podobne premere na prsni višini. Določena je bila vsebnost ekstraktivov, lignina, celuloze in hemiceluloz v beljavi in jedrovini ter skorji debel in vej. Testi so bili izvedeni v skladu s standardi tehničnega združenja za celulozo in papir (TAPPI). Vsebnost lignina, celuloze, hemiceluloz in celokupna vsebnost ekstraktivov je bila primerljiva v lesu debel in vej pri obeh vrstah. Vsebnost celuloze in hemiceluloz je bila pri obeh vrstah manjša v skorji kot v lesu. V beljavi smo zabeležili večjo vsebnost celuloze in hemiceluloz, v jedrovini in skorji pa večjo količino lignina in ekstraktivov. To utegne vplivati na slabšo odpornost beljave proti *škodljivcem*. Študija kaže, da sta jedrovina in skorja obeh vrst *Nesogordonia papaverifera* in *Holarrhena floribunda* lahko vir spojin z visoko dodano vrednostjo.

Ključne besede: strukturne komponente, celokupni ekstrakti, les debla/veje, skorja, *Nesogordonia papaverifera, Holarrhena floribunda*

1 INTRODUCTION
1 UVOD

In the context of tropical forest management, the branches, roots and bark of lesser-known tropical timber species are still underutilized and therefore continue to offer great potential for utilization. At present hundreds of potentially valuable trees are being left behind, often simply to be burnt in forest clearing operations (Boampong et al., 2015).

Nesogordonia papaverifera occurs in numerous forest types except the wet evergreen forests. It is distributed in West Africa and the Central Afri-

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can Republic, and is frequently found in Ghana. It is an evergreen tree on base-rich soils and comes from the family Malvaceae (formerly Sterculiaceae*)* (InsideWood, *Nesogordonia,* 2024) with the international trade name of kotibe, and local name of danta. The trees can be up to 30 m high with narrow sharp buttresses (Arevalo et al., 2020). The tree is harvested from the wild for local use as a medicine and source of wood materials. The heartwood is reddish-brown; it is sharply demarcated from the 5-8 cm wide band of lighter-coloured sapwood. The texture is fine and even, the grain narrowly interlocked, producing a striped figure, lustre is medium, it has no characteristic odour or taste, the wood is marked with dark streaks of scar tissue, and pin knots, it has a slightly greasy feel (Tamboura et al., 2005).

Another interesting tree species, *Holarrhena floribunda* comes from the family Apocynaceae. It has the synonyms *Holarrhena Africana* and *Holarrhena wulfsbergii*, while the vernacular names include the false rubber tree, conessi bark, kurchi bark (En) holarrhène, holarrhène du Sénégal (Fr), and sese (Gh). *Holarrhena floribunda* occurs from Senegal east to Sudan, and south to DR Congo and Cabinda (Angola). It sheds its leaves at the end of the dry season and new leaves appear at the beginning of the rainy season. The flowers appear shortly after the leaves; the flowering period is short. Fruits mature a few months after flowering but do not dehisce until 3–4 months later (Tamboura et al., 2005). *Holarrhena floribunda* coppices well and can survive bushfires by producing suckers from burned-down stumps. *Holarrhena floribunda* occurs in deciduous forests, open localities in dense forest, woodland, and savanna, on clay, sand, lateritic soils, or rocky outcrops, from sea level up to 1000 m altitude. *Holarrhena floribunda* is easily propagated by seed, suckers, or small-diameter cuttings. Fresh seed has a high germination rate but loses its viability after having been stored for a year (Tamboura et al., 2005).

Both species are among the most important commercial tropical timber species in Ghana. In 2019, Ghana exported a total volume of 1,898 m^3 of *N. papaverifera* for €379,876 (3,343,913 cedis) and finished curved products and sculptures of *H. floribunda* species for €976,430 (8,592,591 cedis), respectively (TEDB, 2019). In spite of its economic value, little is known about chemical composition of its stem and branch wood and bark.

Previous investigations of *N. papaverifera* showed that the basic density of wood of different tree parts varied from 700 to 729 kg/m^3 (Antwi et al., 2022). Wood anatomy of the species is described in InsideWood (Wheeler et al., 2010; Wheeler, 2011; InsideWood*, Nesogordonia* 2024). The heartwood of the stems and branches was however rated very durable (Antwi et al., 2022) according to durability classifications (Eaton & Hale, 1993).

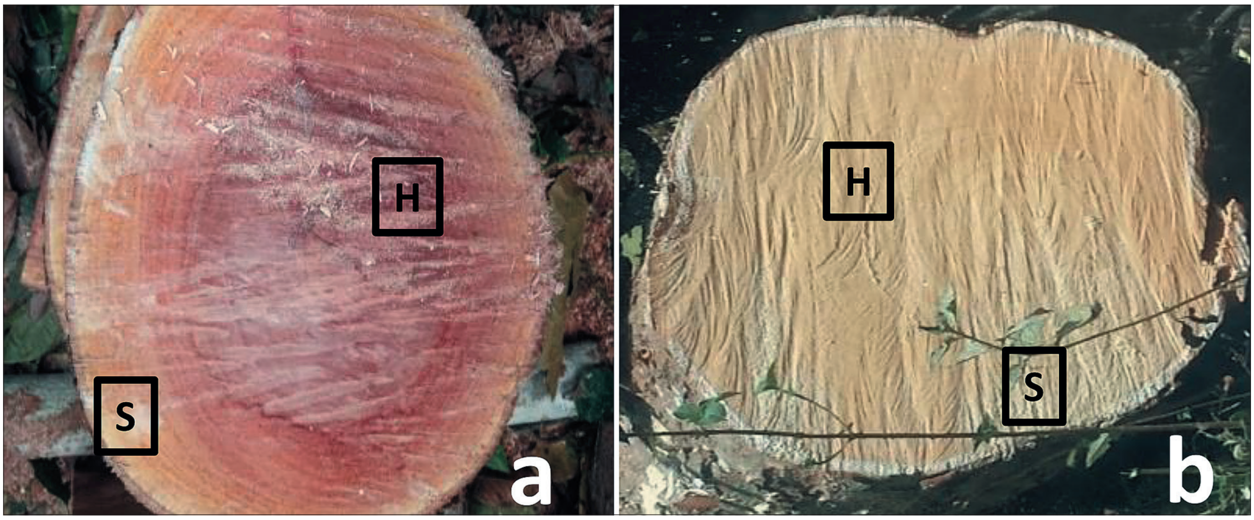

Figure 1. Cross sections of the stems of *Nesogordonia papaverifera* (a) and *Holarrhena floribunda* (b). S – sapwood, H – heartwood.

Slika 1. Prečni prerez debel *Nesogordonia papaverifera* (a) and *Holarrhena floribunda* (b). S – beljava, H – jedrovina.

The basic density of *H. floribunda* wood was found to vary from 456 to 479 kg/m³ (Antwi et al., 2022). The natural durability of *H. floribunda* heartwood of both stems and branches was rated moderately durable (Antwi et al., 2022) according to durability classifications (Eaton & Hale, 1993).

The wood of *N. papaverifera*, as shown in Figure 1a, is suitable for shaving into wood wool for packing fruit, carvings, combs, axe handles, and small utensils (Arevalo et al., 2020). *N. papaverifera* is also mostly used in furniture production and other structural purposes. However, not much has been studied with regard to the chemical composition characteristics across the components and tissues of stem wood, branch wood, and bark of this timber species.

In Ghana *H. floribunda*, as shown in Figure 1b, is mostly used for carving stools for kings, queen mothers, fetish priests, and other prominent persons in society, and is considered to be the best white wood available for these purposes. The wood anatomy of the species is described in InsideWood (InsideWood, *Holarrhena*, 2024).

The objective of this study is to determine the chemical components such as cellulose, hemicellulose, lignin, and total extractives of *N. papaverifera* and *H. floribunda* stem and branch wood and bark.

2 MATERIALS AND METHODS

2 MATERIALI IN METODE

2.1 MATERIALS

2.1 MATERIALI

Five mature trees each of *Nesogordonia papaverifera* (danta) and *Holarrhena floribunda* (sese) were acquired from New Koforidua, in the Ejisu – Juaben Municipality of the Ashanti region within the middle belt of Ghana to provide wood samples for the chemical composition of the structural and non-structural components of the wood and bark of the selected species, mainly because of the availability and accessibility of the trees. The trees were obtained from a cocoa farm in the same locality within the open forest of the area, which lies within latitudes 1° 15'N and 1° 45'N and longitude 6° 15'W and 7° 00'W. It occupies a land area of 637 km² (Ghana Statistical Service, 2021).

In this study, the sampling approach by Bao et al. (2001) was adopted. Trees with similar diameters at breast height were selected for harvesting for both *N. papaverifera* and *H. floribunda* species. The trees were first identified by a technical officer from the Forestry Commission, Juaso District. Fresh and dry leaves and seeds from the trees were collected and sent to the laboratory at the Forest Research Institute of Ghana for the confirmation of the field species identification using the field guide to the forest trees of Ghana by Arevalo et al. (2020). Trees were purposefully selected based on their availability in the farmland, the diameter range of 40-45 cm at the breast height, and the overall straightness of the trunk. Samples were critically examined to ensure that they were free from both natural and artificial defects. Samples were taken specifically from the three portions of the species tissues (the heartwood, the sapwood, and the wood bark) and the tree component (the stem and the branch wood) for their chemical characteristics, as illustrated in Figure 2. *N. papaverifera* exhibited a clear distinction between heartwood and sapwood, but in the case of *H. floribunda* there is no clear distinction between heartwood and sapwood, as shown in Figures 1a and 1b. As a result, the surface of the billets was carefully measured and sawn to ensure the inclusion of heartwood and sapwood portions. The discs of each selected portion were divided into four (i.e. North, South, East, and West) and sawn into three planks (1-3) from the pith portion of the billet to the bark portion to represent the heartwood and sapwood part of the tree after comparing the sawn planks results.

A disc of about 50 cm represents the stem and for a branch, 75 cm from the knot, a disc of 50 cm was extracted from the two branches of each tree

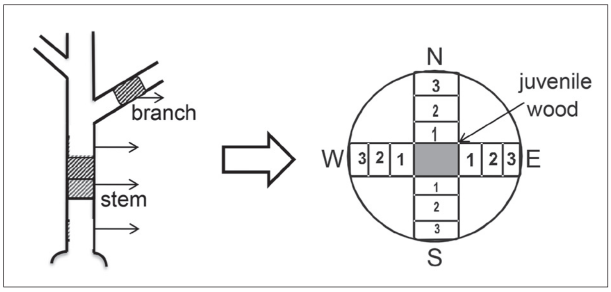

Figure 2. Schematic illustrations, showing how the wood and bark samples were collected from the stem and branches of the trees studied.

Slika 2. Shema, ki prikazuje način vzorčenja lesa in skorje iz debel in vej preučevanih dreves.

to obtain varied diameters of branch wood for the total extractive, hemicellulose, cellulose, and lignin study, as illustrated in Figure 2. This criterion was adopted to ensure the straightness of the branch disc and possibly avoid the inclusion of obvious tension wood.

2.2 CHEMICAL ANALYSIS OF WOOD AND BARK
2.2 KEMIJSKA ANALIZA LESA IN SKORJE

2.2.1 Content of total extractives
2.2.1 Vsebnost celokupnih ekstraktivov

The total extractives were determined in three successive steps: extraction with acetone, extraction with alcohol, and hot water extraction, according to the TAPPI standards. The dried samples were ground into a powder with a Wiley mill to pass a 40-mesh (425µm) sieve and retained in a 60-mesh (250µm) sieve. The extraction was performed using a Soxhlet extractor. After the extraction, the wood samples were air-dried before the determination of their chemical components (TAPPI T207cm-2011).

2.2.2 Lignin content
2.2.2 Vsebnost lignina

Lignin was determined by weighing 1g of extractive-free sample into a conical flask. Fifteen milliliters of cold sulfuric acid (72%) was then added slowly while stirring, and mixed well. The reaction proceeded for two hours with frequent stirring in a water bath maintained at 18-20°C. After two hours the specimen was transferred by washing it with 560ml of distilled water into a 1,000 ml flask, diluting the concentration of the sulfuric acid to 3%. A condenser was attached to the flask and the insoluble material was allowed to settle. The contents of the flask were filtered by vacuum suction into a fritted-glass crucible of known weight. The residue was washed with 500ml of hot tap water and then oven-dried at 103°C. The crucible was then cooled in a desiccator and weighed until a constant weight was obtained (TAPPI T222cm-2011).

2.2.3 Cellulose content
2.2.3 Vsebnost celuloze

Cellulose was determined by weighing 1.5g of the hemicellulose into a 250ml Erlenmeyer flask with a small watch glass cover. The flask was placed into a water bath at 25°C and 100ml of 17.5% NaOH solution was added with thorough stirring. After 30 minutes of stirring, 100ml of water was added and stirring was continued for another 30 minutes. The Erlenmeyer flask was removed and filtered with a fritted-glass crucible of known weight. The residue was washed with 25ml of 9.45% NaOH solution and then with 40ml of 10% acetic acid, and finally washed free of acid with plenty of water. The residue was oven-dried in an oven at 103°C, cooled in a desiccator, and weighed until a constant weight was reached (TAPPI T203cm-2011).

2.2.4 Hemicellulose content
2.2.4 Vsebnost hemiceluloz

Hemicellulose content was determined by weighing 2g of extractive-free sample in a 250ml conical flask with a small watch glass cover. The sample was then treated with 180ml of distilled water, 8.6g of sodium acetate, 6.0ml of acetic acid, and 6.6g of sodium chlorite. The sample was covered and placed in a hot-water bath for 3 hours. The samples were filtered into a coarse porosity-fitted glass of known weight and washed free of ClO_2 with distilled water. The crucible was oven-dried at 103°C, cooled in a desiccator, and weighed until a constant weight was reached.

2.3 STATISTICAL PROCEDURES
2.3 STATISTIČNA OBDELAVA PODATKOV

The data were checked for statistical significance using Origin statistical software (Version 9.0 Pro. software). A descriptive statistical tool was used to summarize the data numerically. The Tukey Multiple Comparison Test was used to test the statistical significance of each pair of means and the variation in the quantitative structural elements and total extractive. The Tukey HSD post-hoc tests were done to identify which of the pairs of treatments are significantly different from each other.

3 RESULTS AND DISCUSSION
3 REZULTATI IN RAZPRAVA
3.1 VARIABILITY OF THE CONTENT OF STRUCTURAL COMPONENTS AND EXTRACTIVES IN WOOD AND BARK
3.1 VARIABILNOST V VSEBNOSTIH STRUKTURNIH KOMPONENT IN EKSTRAKTIVOV V LESU IN SKORJI
3.1.1 Total extractives
3.1.1 Količine ekstraktivnih snovi

The cold-water-soluble samples of both stem and branch contained a more extractives than the hot-water-soluble samples. Ethanol soluble matter was slightly higher than the acetone soluble matter. The mean total extractives of bark, heartwood, and sapwood for the stem and branch of the species are shown in Table 1. For *N. papaverifera,* the stem wood recorded a total of 8.19% and 6.85% for the branch wood. *H. floribunda* recorded a total of 7.23% for the stem and 6.34% for the branch wood. For the radial variation, the bark contained higher extractives followed by the heartwood and sapwood. These differences in extractive content between the tissues have been known and scientifically proven for more than four decades. For the tree chemical components, the stem contained a higher content than the branch in both species but the differences are not significant.

The results show that the bark and heartwood contain a greater amount of extractives than the sapwood. This pattern was the consequence of the radial distribution of dichloromethane soluble, which had a peak concentration at the heartwood-sapwood transition (6.0%) and decreased to very small values in the outer sapwood (1.0%), as reported by Mayer et al. (2006). Polar compounds (ethanol and water-soluble) increased in sapwood and the largest concentrations were found closest to the bark. The differences between the bark, sapwood, and heartwood samples of the species studied are associated with the metabolic activities observed in the transition zone related to heartwood formation, with enzymatic hydrolysis of triglycerides and an increase in fatty acids during the process of parenchyma cell death (Piqueras et al., 2020). This type of radial variation of extractives has already been reported in other species, for example, Vek et al. (2020) investigated the amounts of hydrophilic extractives in bark and wood samples of black locust stem (*Robinia pseudoacacia L.*) and found that the concentrations of extractives were highest in the outermost samples of heartwood. Significantly less hydrophilic compounds were extracted from bark and sapwood samples. They reported that heartwood of black locust can be considered a source of value-adding compounds. The investigation showed significant variability in the content of extractives in the radial direction and less pronounced variability in the axial direction. Dünisch et al. (2010) reported that, based on extractive content, the formation of juvenile wood in black locust is restricted to the first 10–20 years of cambial growth. In mature heartwood, high contents of phenolic compounds and flavonoids were present, localized in high concentrations in the cell walls and cell lumen of axial parenchyma and vessels. In juvenile wood, the content of these extractives is significantly lower.

This pattern explains the variation in natural durability in the selected species where heartwood is more durable than sapwood. The results that show the bark and heartwood contain a greater amount of extractives than the sapwood (Kai, 1991).

The quantity of total extractives in wood is highly variable and can range from 3-30% by weight depending on the tree species (Desch & Dinwoodie, 2016), as was observed by this study. Roger (2012) noted that they usually range from 2–10% by dry weight and up to 40% in some timbers, the percentage extractives reported in Table 2 were higher in the stem wood than branch wood of the species, consistent with the report by Samariha and Kiaei (2011) for *Ailanthus altissima*. The higher extractive content may offer the heartwood of stem wood and branch wood better durability with regard to fungus infestation, and minimize the severity of attack by destructive organisms (e.g. termites), as reported by Quartey (2009). However, the sapwood portions of the studied species would have greater pulp yield, but less natural durability than their comparable heartwood portions. Moreover, the higher extractive content may be attributed to the attack of the tree by the shoot borer, which resulted in the large production of extraneous material to protect itself against the attack.

Table 1. Content of extractives in stem and branches as well as in different tissue categories (heartwood, sapwood and bark) of *Nesogordonia papaverifera* and *Holarrhena floribunda.*
Preglednica 1. Vsebnost ekstraktivov v deblu in vejah ter v različnih kategorijah tkiv (jedrovina, beljava in skorja) *Nesogordonia papaverifera* in *Holarrhena floribunda.*

Species	Tree component	Species tissue	Mass fraction of extractives (%) in:			
			Coldwater	Hot water	ASM	ESM
Nesogordonia papaverifera	Stem	Bark	17.50 (2.84)	14.65 (1.30)	4.09 (0.59)	5.87 (1.00)
		Sapwood	9.09 (0.67)	7.43 (1.82)	1.95 (1.24)	2.93 (0.61)
		Heartwood	15.86 (2.01)	11.40 (1.78)	3.87 (0.69)	3.74 (0.43)
		Average	14.15 (1.84)	11.16 (1.63)	3.30 (0.84)	4.18 (0.68)
						8.19
	Branch	Bark	14.85 (3.06)	13.46 (2.05)	2.69 (0.89)	3.27 (1.05)
		Sapwood	8.06 (1.86)	7.22 (1.64)	1.40 (0.52)	1.59 (0.24)
		Heartwood	12.34 (2.89)	11.87 (1.94)	2.80 (0.83)	2.78 (0.72)
		Average	11.75 (2.60)	10.85 (1.87)	2.29 (0.74)	2.54 (0.67)
						6.85
Holarrhena floribunda	Stem	Bark	15.56 (2.02)	13.23 (3.09)	4.23 (1.16)	6.12 (1.64)
		Sapwood	7.39 (1.74)	5.74 (1.13)	1.08 (0.78)	1.88 (0.48)
		Heartwood	12.79 (2.43)	11.59 (2.21)	3.92 (0.64)	3.37 (1.56)
		Average	11.91 (2.06)	10.18 (2.14)	3.07 (0.86)	3.79 (1.22)
						7.23
	Branch	Bark	14.77 (2.51)	12.74 (2.49)	2.55 (0.90)	4.30 (1.81)
		Sapwood	7.01 (2.17)	5.15 (0.96)	0.51 (0.31)	0.72 (0.44)
		Heartwood	12.08 (0.91)	11.87 (1.89)	2.22 (0.46)	2.25 (0.39)
		Average	11.28 (1.86)	9.92 (1.77)	1.76 (0.55)	2.42 (0.88)
						6.34

~Standard deviations in parentheses. ASM=Acetone soluble matter, ESM=Ethanol soluble matter

3.1.2 Lignin
3.1.2 Lignin

Lignin content in the heartwood of *N. papaverifera* and *H. floribunda* stem wood and branch wood was comparable to that in the bark tissue, but much lower lignin content was found in the sapwood of both species. A significant difference ($p<0.05$) exists between the bark and sapwood and heartwood. The stem wood contained higher values than the branch wood, but the differences were not significant. However, for *H. floribunda* species, the branch wood contained a slightly higher value than the stem wood but the difference is not significant at a 5% level of probability, as shown in Table 2.

The stem wood contained higher lignin than the branch wood for both selected timber species. Similar to what Samariha and Kiaei (2011) reported, there was a greater percentage of lignin in the stem wood compared to the branch wood of *Ailanthus altissima*. This study also confirms an earlier report by Ververis et al. (2004) which found that the content of chemical components, and especially lignin, in wood depends on tissue maturity, and the literature says there is a general tendency for a decrease in lignin as we move from the base of the tree to the top (Mitsuhashi, 2007). This corresponds to a greater lignin percentage in the stem than the branch from this study, in which the stem is expected to have older tissues such as fibres, parenchyma, and vessels than the branch. Again, Mitsuhashi (2007) noted that the amount of lignin in wood usually decreases from the heartwood to the sapwood and from the base of the tree to the crown. The lignin content observed in this study was greater in heartwood than sapwood, supporting Miranda et al. (2007) and Sitsofe (2016), who reported lower lignin content in the sapwoods of *Eucalyptus globulus*, *Eucalyptus nitens*, *Terminalia ivorensis,* and *Vachellia robusta.* However, the bark has more lignin followed by the heartwood and the sapwood portions in this study. This was expected since mature tissues (at the base) accumulate higher amounts of metabolic products than the younger parts at the top, as reported by Mitsuhashi (2007).

3.1.3 Cellulose
3.1.3 Celuloza

The cellulose content in the sapwood of *N. papaverifera* and *H. floribunda* stem wood and branch wood was comparable to that in the bark tissue, although a much lower cellulose content was found in the heartwood of the species. A significant difference ($p<0.05$) exists between the sapwood and heartwood, and the bark and the heartwood. The branch wood contained higher values than the stem wood, but the differences were not significant ($p<0.05$), as shown in Table 2.

The branch-sap/heartwood portion of the species contained a higher cellulose content than the stem sap/heart portion. This agrees with Magel (2000), which found that there is a greater cellulose percentage for sapwood than the heartwood. Comparing this result with earlier reports by Mitsuhashi (2007) and Raniati (2016), the data from the current study fall within the reported range. According to the rating system designated by Nieschlag et al. (1960), plant material with 34% and higher alpha-cellulose content can be characterized as promising for pulp and paper manufacture from a chemical composition point of view. As the principal food for termites, wood structures that contain excessive alpha-cellulose and moisture content are avidly consumed and destroyed by these insects (Peralta et al., 2003). With regard to their cellulose contents, the stem and branch sapwood of both *N. papaverifera* and *H. floribunda* could be suitable for the production of pulp and paper. The amount of cellulose and excessive moisture content at the sap portions within the two species could be factors that attract bio-degradation (i.e. termites) to attack the sapwood portion, making this less durable than the heartwood portion, as observed in our previous study on the termite resistance of stem and branch wood of these species (Antwi et al., 2020)

3.1.4 Hemicellulose content
3.1.4 Vsebnost hemiceluloz

The hemicellulose content in the sapwood of *N. papaverifera* stem wood and branch wood was comparable to that in the bark tissue, although much lower hemicellulose content was found in the heartwood of the species. A significant difference ($p<0.05$) exists between the sapwood and heartwood, and the bark and heartwood. The branch wood contained more hemicellulose than the stem wood, but the differences were not significant ($p<0.05$), as shown in Table 2.

The hemicellulose content for the stem and branch wood portions shows that the branch wood contained a higher percentage of hemicellulose than the stem wood portions for both species, similar to the findings of an earlier report by Magel (2000) which stated that there is more hemicellulose in branch wood than stem wood. In the species tissues in the radial direction, the sapwood had a greater amount of hemicellulose than the heartwood. This also supports Magel (2000), who found that heartwood has less hemicellulose content than sapwood. Mitsuhashi (2007) observed that hemicellulose in softwoods ranges from 25-30% and in hardwoods from 30-35%, and the results are within the range (28-34%) identified by Mitsuhashi (2007) for hardwoods. Bowyer et al. (2003) reported that the amount and type of hemicellulose within timber species depend on the kind of wood and the position along the stem, and this was observed within the branch and the stem of the two-timber species included in this study.

Table 2. Chemical analysis of tree components (stem and branch) and tissues (heartwood, sapwood, bark) of *Nesogordonia papaverifera* and *Holarrhena floribunda.*

Preglednica 2. Kemijska analiza drevesnih komponent (debla in vej) in tkiv (jedrovina, beljava, skorja) *Nesogordonia papaverifera* in *Holarrhena floribunda.*

Species	Tree part	Chemical compound (%)	Tissues			
			Bark	Sapwood	Heartwood	Average
Nesogordonia papaverifera	Stem	Lignin	30.45**a** (2.07)	25.85**b** (1.84)	32.95**a** (4.76)	29.75 (5.23)
		Cellulose	31.62**a** (3.67)	32.82**a** (4.94)	27.71**b** (2.38)	30.71 (3.43)
		Hemicelluloses	32.67**a** (3.67)	33.23**a** (4.94)	28.17**b** (3.24)	31.35 (2.63)
	Branch	Lignin	29.87**a** (1.09)	26.85**b** (2.54)	31.90**a** (3.42)	29.54 (2.06)
		Cellulose	33.60**a** (5.31)	33.84**a** (3.26)	28.14**b** (3.26)	31.86 (3.83)
		Hemicelluloses	34.15**a** (5.42)	33.10**a** (3.82)	28.00**b** (4.06)	31.75 (5.26)
Holarrhena floribunda	Stem	Lignin	31.64**a** (4.86)	25.20**b** (3.03)	31.00**a** (3.08)	29.28 (2.16)
		Cellulose	31.60**a** (2.96)	34.00**a** (2.44)	29.40**b** (5.32)	31.33 (3.35)
		Hemicelluloses	32.95**a** (2.96)	34.43**a** (3.54)	29.10**b** (5.31)	32.16 (4.35)
	Branch	Lignin	32.00**a** (3.89)	26.40**b** (2.61)	30.62**a** (2.35)	29.67 (2.53)
		Cellulose	32.85**a** (2.70)	33.25**a** (3.35)	27.95**b** (1.02)	31.35 (3.90)
		Hemicelluloses	34.19**a** (2.70)	34.95**a** (5.02)	28.78**b** (2.47)	32.64 (4.16)

~Mean values in different letters (**a** and **b**) indicate a significant difference ($P<0.05$)
~Standard deviations in parentheses

4 CONCLUSIONS
4 SKLEPI

Generally, the chemical characteristics of the branch wood of the species studied are comparable with their stem wood and other most known species used for structural applications in Ghana. The cellulose and hemicellulose contents were higher in sapwood than in heartwood and in branch wood than in stem wood. However, the lignin and extractive content of both species was higher in heartwood than in sapwood and in stem wood than in branch wood. The content of cellulose and hemicelluloses was lower in bark than in wood.

The lignin, cellulose, hemicellulose, and total extractive content are comparable in stem wood and branch wood in both species, *N. papaverifera* (danta) and *H. floribunda,* like in the well-known wood species such as *Leuceana leucocephala* and *Moringa perigrina* woods that are used in the production of pulp for the paper industry in Ghana. The content of cellulose and hemicellulose was lower in bark than in wood in both species.

For radial variation, the sapwood recorded a greater value of cellulose and hemicellulose content than the heartwood. However, the heartwood and bark recorded a greater amount of lignin and total extractive content than the sapwood.

While the biomass of the Ghanaian tree species studied here is usually described as less utilizable, this report shows that the wood and bark of these species are useful and could be a source of valuable bioactive phytochemicals, but this needs further investigation.

5 SUMMARY
5 POVZETEK

Določili smo kemično zgradbo in količino ekstraktivov v deblih, vejah in skorji dveh tropskih listavcev *Nesogordonia papaverifera* (kotibe, danta) in *Holarrhena floribunda* (holarhena, sese) iz Gane. Določili smo količino ekstraktivov, lignina, celuloze in hemiceluloz.

Pet zrelih dreves vsake od obeh vrst smo posekali v območju New Koforidua v občini Ejisu-Juaben v regiji Ashanti v srednjem pasu Gane na kmetiji kakava in v odprtem gozdu območja, približne koordinate 1°15'J do 1°45'J, 6°15'Z in 7°00 Z.

Vzorčili smo v skladu z metodologijo, ki so jo uporabili Bao in sodelavci (2001). Drevesa so imela podobne premere v prsni višini. Drevesa je prvi določil tehnični uradnik iz komisije za gozdove okrožja Juaso. Sveže in suhe liste in semena z dreves so zbrali in poslali v laboratorij na Inštitutu za gozdne raziskave Gane za potrditev identifikacije drevesnih vrst z uporabo terenskega vodnika po gozdnih drevesih Gane (Arevala et al., 2020). Drevesa so bila izbrana glede na njihovo razpoložljivost na kmetijskem zemljišču, razponi premerov so bili 40–45 cm v prsni višini. Pri vzorčenju smo izbrali ravna debla. Vzorci so bili pregledani, da bi zagotovili, da so brez napak. Odvzeti so bili iz beljave in jedrovine debla in vej.

Iz debla smo odvzeli hlodiče dolžine približno 50 cm in iz vej kolute približno 75 cm od nastavka prve in druge veje vsakega drevesa. Vzorčili smo tako, da so bili hlodiči čim bolj ravni, s čim manj tenzijskega lesa in drugih napak. Vsi testi so bili izvedeni v skladu z navodili standardiziranega tehničnega združenja za celulozo in papir (TAPPI), razen za topnost lesa v alkoholu in benzenu. Pri določanju količine ekstraktivov je prišlo do manjše spremembe. Namesto alkohola in benzena je bil zaradi varnosti uporabljen aceton.

Za določitev osnovne statistike in statističnih razlik smo podatke obdelali s statističnim programom Origin (različica 9.0 Pro.).

Ugotovljenih je bilo več v hladni vodi topnih ekstraktivnih snovi kot tistih, topnih v vroči vodi. Snovi, topnih v etanolu, je bilo nekoliko več kot snovi, topnih v acetonu. Topilo diklorometan je bilo uporabljeno za določanje sterolov, maščobnih kislin in voskov, v skladu s standardom TAPPI T204cm-97 za komponente lesa debel in vej za obe vrsti. Povprečni celokupni ekstraktivi skorje, jedrovine in beljave so prikazani v preglednici 1. Skorja je imela največ ekstraktivnih snovi, sledile so količine v jedrovini in nato v beljavi. V deblih je bilo pri obeh vrstah več ekstraktivnih snovi kot v vejah, vendar razlike niso bile statistično značilne.

Les vej je imel višji odstotek hemiceluloz kot deblo in skorja. Vsebnost celuloze je bila višja v beljavi in nižja v jedrovini. Les vej je imel več celuloze kot les debla, vendar razlike niso bile statistično značilne ($p<0,05$). Vsebnost lignina je bila višja v jedrovini in nižja v beljavi obeh vrst. Les debla je imel več lignina kot les vej, vendar razlike niso bile statistično značilne. Izvlečki skorje in jedrovine vrste *N. papaverifera* se lahko uporabljajo za zaščito lesa beljave nekaterih drugih drevesnih vrst.

Ker se šteje, da je biomasa preučevanih lesnih vrst iz Gane slabo uporabna, ta študija kaže, da sta les in skorja obeh vrst uporabna in bi lahko bila vir dragocenih bioaktivnih fitokemikalij, vendar je ta potencial treba dodatno raziskati.

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CHEMICAL PROPERTIES OF *Terminalia catappa* WOOD

KEMIJSKA ZGRADBA LESA VRSTE *Terminalia catappa*

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Abstract / Izvleček

Abstract: Ghana's forest is fast depleting as a result of over-dependency on the traditionally known timber species and high demand for wood products for structural works. This study seeks to determine the chemical properties and basic density of *Terminalia catappa* wood and its potential for structural application. Three mature trees of *Terminalia catappa* were acquired based on the diameter at the breast height (dbh) greater than 40 cm. In this study 160 samples of wood were used for the chemical properties and density tests. Chemical analyses were performed by using the TAPPI standards. The study revealed that there were higher cellulose and hemicellulose contents in the sapwood than in heartwood, and in the branchwood than in stemwood. Lignin and extractives content were higher in the heartwood than in sapwood, and in the stemwood than in branchwood. The basic density of the sapwood ranged from 473 to 649 kg/m³ and in the heartwood from 444 to 579 kg/m³ being the highest in the base portion and the lowest in the branches. The difference in wood density, which is greater in the base area than the branches, emphasizes how crucial it is to take wood quality into account for the best possible use across various tree portions. The study also clarifies the wood's suitability for structural and non-structural uses. These findings have the potential to influence sustainable forest management strategies and encourage the use of alternative timber to supplement the resource base.

Keywords: *Terminalia catappa*, wood, cellulose, hemicellulose, lignin, extractives, stemwood, branchwood

Izvleček: Gozdovi Gane se zaradi prevelike odvisnosti od tradicionalnih lesnih vrst in velikih potreb po lesnih izdelkih za gradbeništvo hitro krčijo. Namen te študije je določiti kemijske lastnosti lesa vrste *Terminalia catappa* in njen potencial za uporabo v gradbeništvu. Za raziskave smo uporabili tri odrasla drevesa vrste *Terminalia catappa* s premerom v prsni višini nad 40 cm. Za različne teste je bilo uporabljenih 160 vzorcev ali ponovitev. Kemijske lastnosti vzorcev smo preučili v skladu s TAPPI standardi. Študija je pokazala, da je bila vsebnost celuloze in hemiceluloz večja v beljavi kot v jedrovini in večja v vejah kot v deblu. Vsebnost lignina in ekstraktivov je bila višja v jedrovini kot v beljavi in višja v deblu kot v vejah. Osnovna gostota beljave je bila od 473 do 649 kg/m³, jedrovine pa od 444 do 579 kg/m³, pri čemer je bila najvišja v spodnjem delu debla, najnižja pa v vejah. Razlike v gostoti lesa kažejo, kako pomembno je upoštevati lastnosti lesa iz različnih delov drevesa, za najboljšo možno uporabo. Študija nakazuje tudi primernost lesa za konstrukcijske in nekonstrukcijske uporabe. Te ugotovitve so pomembne za strategijo trajnostnega gospodarjenja z gozdovi in spodbujajo uporabo lesa manj znanih lesnih vrst za pokrivanje potreb po lesu.

Ključne besede: *Terminalia catappa*, les, celuloza, hemiceluloze, lignin, ekstraktivi, les debla, les vej

1 INTRODUCTION

1 UVOD

Over-dependence on the traditionally known timber species such as odum or iroko (*Milicia excelsa*), ofram or limba (*Terminalia superba*), wawa or samba (*Triplochiton scleroxylon*) and the high demand for wood products in the timber industry in Ghana has led to the over-exploitation of these traditionally known timber species (Obiri et al., 2019). As a result, many researchers are looking for other,

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alternative materials, such as the use of agricultural waste for the production of fibre board and lightweight wood panels, and the use of lesser-known and lesser-utilized timber species to replace the traditionally known ones (Ndulue et al., 2023). For example, Appiah-Kubi et al. (2016) studied the mechanical properties of four lesser-known Ghanaian wood species and showed that timber of the lesser-known wawabima (*Sterculia rhinopetala*), akye (*Blighia sapida*), awiemfosemina (*Albizia ferruginea*) and bediwonua (*Canarium schweinfurthii*) could also be used for structural work.

Terminalia catappa, with the common names of sea almond, ketapang, and tropical almond tree, is one of the lesser-known tropical tree species of the Combretaceae family that grows mainly in the tropical regions of Asia, Africa, and Australia (Pham & Bechtold, 2023). The tropical almond tree grows up to 40 m with upright and horizontal branches. Its branches are characteristically arranged in a symmetrical crown tier. The leaves are large, broad, and ovoid-shaped, and generally have a dark green colour. It is a monoecious plant, with male and female flowers found on the same plant. The fruit is

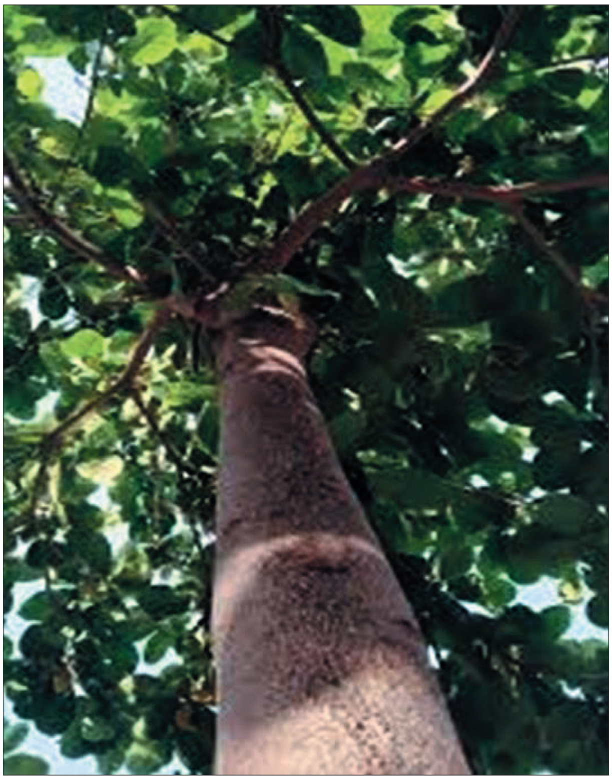

Figure 1. *Terminalia catappa* tree.
Slika 1. Drevo vrste *Terminalia catappa.*

ovoid-shaped with a single seed. The fruit appears green in colour when raw, but when it ripens it turns into a reddish-yellow colour. The seed is edible when the fruit ripens. *Terminalia catappa* is one of the lesser-known and a less utilized timber species abundant in Ghana, and grows to utilizable timber size (Habibullah et al., 2023; Fasona et al., 2022).

There have been several studies on *Terminalia catappa.* Ben et al. (2021) studied the antioxidant properties of *Terminalia catappa* leaves and indicated that the plant has numerous medicinal properties, including anti-indigestion, antimicrobial, antifungal, anticancer, diaphoretic, anti-dysentery, antibacterial, antidiabetic, anthelmintic, haematological and antitumor activities. A study by Ihuma et al. (2021) revealed that extracts from the leaves contain bioactive constituents with high antimicrobial activity against salmonella, and could potentially possess rich medicinal constituents when subjected to further chemical and pharmacological studies. Devi et al. (2019) presented *Terminalia catappa* as herbal biomedicine in the aquaculture industry in India, and indicated that the extract from the leaves can be used to treat tilapia fish ectoparasites. Dianala (2019) studied the utilization of the extracted substances from the *Terminalia catappa* in Thailand and showed that leaves are rich in tannins and organic compounds that help in conditioning the culture water, resulting in improving survival, growth and health of cultured aquatic species.

The study of Oduro et al. (2009) on the proximate composition and basic photochemical assessment of the two common varieties of *Terminalia catappa* trees in Ghana (red and yellow varieties) revealed that the nut of both varieties has promising medicinal and nutritive properties. Islam et al. (2008) also studied some physical (density, moisture content) and mechanical (static bending, compression and tension parallel to grain and screw withdrawal test) properties of *Terminalia catappa* wood and suggested that the timber is moderately or medium dense and can be used as a structural material, fuel or industrial raw material. Quartey et al. (2022) indicated that *Terminalia catappa* has a medium-density wood with medium strength, elasticity and rupture, but high shear strength.

This study seeks to determine chemical properties of wood from different parts of a tree (stem and branches). For this purpose, analyses of made of the cellulose content, hemicellulose content, extractives content, and basic density of stemwood and branchwood.

2 MATERIALS AND METHODS
2 MATERIALI IN METODE
2.1 MATERIALS
2.1 MATERIALI

Three *Terminalia catappa* trees of similar diameters at breast height (dbh) were identified by the researchers, assigned a GPS Code (CU-1278-9796), and selected for harvesting (Figure 1). Three trees with a diameter at breast height greater than 40 cm and heights greater than 15 m were felled.

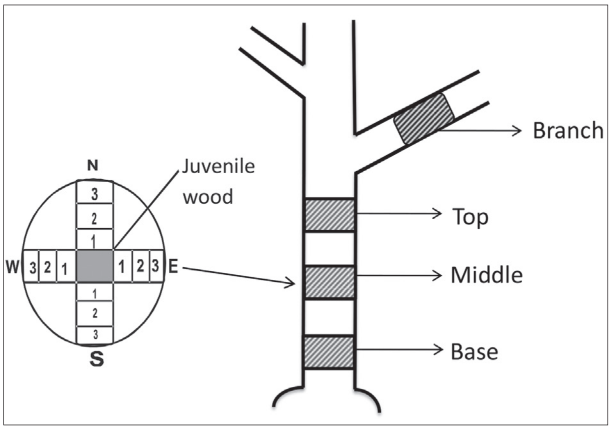

Figure 2. Schematic illustrations, showing the sampling of wood from the stem and branches.
Slika 2. Shema odvzema vzorcev lesa iz debla in vej.

Figure 3. Harvesting and wood sampling from *Terminalia catappa* trees at Dunkwa-on-Offin.
Slika 3. Posek in vzorčenje lesa iz dreves *Terminalia catappa* v območju Dunkwa-on-Offin.

Figure 4. Samples (discs) of *Terminalia catappa* wood from the different parts of the tree.
Slika 4. Vzorčni diski z različnih delov drevesa *Terminalia catappa.*

The full lengths of the tree stems were divided into three equal parts and demarcated with permanent makers and 50 cm from the knot a portion of 1.5 m was extracted from the first and second branches of each tree to obtain varied diameters of branch wood for the study (Figure 2). Discs of about 50 cm thickness at breast height and 70 cm from the branch of each tree were taken for chemical investigations (Figures 3, 4). The mean lengths of the clear bole between the first butt-end, middle portion and top portion of each stem were measured and recorded. The recorded average lengths were 1,809 cm. This criterion was adopted to ensure the straightness of the stem discs and possibly avoid the inclusion of obvious tension wood.

The following tools and machinery were used in the harvesting and processing of the specimens: tape measure, band saw, circular saw machine, vernier caliper, electric oven, climate chamber and electronic balance.

2.2 CHEMICAL PROPERTIES
2.2 KEMIJSKE LASTNOSTI

The samples for the chemical analysis were prepared, air-dried and placed in a Wiley mill and milled. Each material was then placed in a shaker with sieves to pass through a 40-mesh sieve (425 µm), then retained on a 60-mesh sieve (250 µm) and stored for chemical analyses. About 10 g air-dried *Terminalia catappa* milled sample that passed through a number 60 (250 µm) sieve and then retained by a number 80 (180 µm) sieve was placed in an extraction thimble ensuring that it did not extend above the level of the top of the siphon tube. The sample was extracted for 4 hours with an ethanol-acetone mixture (1 : 2) in the Soxhlet extraction apparatus. The excess solvent was removed with suction and the wood in the thimble was held with ethanol to remove the excess acetone. The sample in the thimble was returned to the extractor and extraction continued with 95% ethanol (about 200 ml) for 4 hours until the ethanol siphoned over colourless. The sample was removed from the thimble and spread out on a thin layer and allowed to dry in the air until it was free of alcohol. The dried alcohol-free sample was returned to the thimble and extracted with 200 ml of hot water for 4 hours, the same as was done previously using ethanol. After hot water extraction the material was air-dried thoroughly and used as extractive-free material for the determination of lignin, cellulose and hemicellulose.

All tests were conducted under the TAPPI standards, except for the alcohol benzene solubility of wood. There was a minor modification for the extractive content test. Instead of benzene, acetone was used. The ethanol-benzene method was reclassified as Classical by committee action in 1997, and revised by a Standard-Specific Interest Group (SSIG) vote in 2006. Revisions in this version were due to safety concerns about the use of benzene; in this revision, the chemicals were changed from benzene and ethanol to acetone. The moisture content was expressed as a percentage weight loss on drying. About 2 g of air-dried sample from the sap- and heartwood of the stem and branch of each tree was weighed and oven dried at 105 °C for several hours to a constant weight. The experiment was done in three replications and an average of the three replicates was taken. The percentage weight loss on drying was then calculated (TAPPI T264 cm-2007). The total extractives were determined in three successive steps, an extraction with acetone, an extraction with alcohol, i.e. ethanol, and a hot water extraction, according to the TAPPI standard (TAPPI T207cm-2008). The amount of extractive content was measured gravimetrically and expressed as a percentage on the bases of dry samples.

Holocellulose content was determined by weighing 2 g of extractive-free sample in a 250 ml conical flask with a small watch glass cover. The sample was then treated with 180 ml of distilled water, 8.6 g of sodium acetate, 6.0 ml of acetic acid and 6.6 g of sodium chlorite. The sample was covered and placed in a hot-water bath for 3 hours. The samples were filtered into a coarse porosity-fitted glass of known weight and washed free of CIO_2 with distilled water. The crucible was oven–dried at 103 °C, cooled in desiccators, and weighed until a constant weight was reached. The amount of holocellulose content was measured gravimetrically and expressed as a percentage on the bases of dry samples.

Cellulose was determined by weighing 1.5 g of the holocellulose into a 250 ml Erlenmeyer flask with a small watch glass cover. The flask was placed into a water bath at 25 °C and 100 ml of 17.5%

NaOH solution was added thorough stirring. After 30 minutes of stirring, 100ml of water was added and stirring continued for another 30 minutes. The Erlenmeyer flask was removed and filtered with a fritted-glass crucible of known weight. The residue was washed with 25ml of 9.45% NaOH solution and then with 40 ml of 10% acetic acid, and finally washed free of acid with plenty of water. The residue was oven-dried in an oven at 103 °C, cooled in desiccators, and weighed until a constant weight was reached (TAPPI T203cm-2007). The quantity of cellulose was expressed as a percentage based on the moisture-free sample.

Lignin was determined by weighing 1 g of extractive-free sample into a conical flask. Fifteen ml of cold sulphuric acid (72%) was slowly added while stirring and mixing very well. The reaction proceeded for two hours with frequent stirring in a water bath maintained at 18 °C–20 °C. When the two hours had expired, the specimen was transferred by washing it with 560 ml of distilled water into a 1,000 ml flask, diluting the concentration of the sulfuric acid to three percent. A condenser was attached to the flask and the insoluble material was allowed to settle. The contents of the flask were filtered by vacuum suction into a fritted glass crucible of known weight. The residue was free of acid with 500 ml of hot tap water and then oven-dried at 103 °C. Crucibles were then cooled in desiccators and weighed until a constant weight was obtained (TAPPI T222cm-2011). The weight of lignin was then expressed based on the moisture-free sample.

2.3 WOOD DENSITY
2.3 GOSTOTA LESA

The wood density and moisture content were determined according to ASTM D2395-07 and ASTM D4442-07, respectively. The same samples were used for both tests. Each strip was sawn into 20 mm x 20 mm sections and cross-cut into 20 mm cubes. The mass of the samples was taken immediately after preparation using a VWR Science Education RS232 digital electronic balance (with a precision of 0.001g) to obtain the initial mass (W_1). The samples were then soaked in water for 24 hours to obtain the swollen volume (V_1), which was determined by the immersion method. According to Archimedes' principle, the increase in the mass of water displaced by the submerged wood sample is numerically equal to the volume of water displaced. Afterward, the wood samples were oven-dried at 103 ± 2 °C with intermittent weighing until constant mass, and oven-dry mass (W_0) was attained (ASTM D 2395-07). The test was done under an ambient temperature condition of 20 ^{0}C. The test duration was within 24 hours. The basic density (BD) of the samples was then calculated.

3 RESULTS AND DISCUSSION
3 REZULTATI IN DISKUSIJA

3.1 CHEMICAL COMPOSITION OF STEM AND BRANCH WOOD
3.1 KEMIJSKA SESTAVA LESA DEBLA IN VEJ

Table 1 presents the mean chemical composition of the stemwood and branchwood of the studied species with variations of the chemical composition in the sapwood and heartwood. The lignin, cellulose and hemicellulose contents in the branchwood and stemwood showed moderate variation across the species. We found statistically significant differences in the chemical composition between the sapwood and the heartwood portions for both the stemwood and the branchwood.

The average lignin contents in the stemwood was lower in the sapwood (21.45 ± 1.22%) than in the heartwood (24.95 ± 1.08%), and the differences were statistically significant ($P>0.05$). A similar trend was observed in the branchwood of *Terminalia catappa* where the lignin content was significantly lower in the sapwood (22.55 ± 1.21%) than in the heartwood (24.13 ± 1.10%).

This agrees with other studies, for instance the one of Gonzalez and Mitsuhashi (2007) who noted that the amount of lignin in wood usually decreases from the heartwood to the sapwood and from the base to the crown. Similarly, Gominho (2003), Mariani et al. (2005), Miranda et al. (2007), Sitsofe (2016) recorded lower lignin contents in sapwoods of *Eucalyptus globulus*, *Eucalyptus nitens, Quercus* sp., *Terminalia ivorensis* and *Acacia robusta.* According to Iversen and Wannstrom (1986), lignin decreases the permeation of water through the cell walls of the xylem, thereby playing an intricate role in the transport of water and nutrients, and also impedes the penetration of destructive enzymes through the cell wall and protects cellulose and hemicellulose from degradation. Hence, the resistance of the wood structures is largely influenced by lignin (Majaila, 2000).

Cellulose is the main constituent of wood carbohydrates and forms the structural framework of the cell, making up 40% to 50% of total components in hardwoods (e. g., Rózanska et al., 2011; Cole, 2012). The average cellulose content of the stemwood was 32.22% ± 1.21 and of the branchwood 33.10% ± 1.09, respectively (Table 1). The cellulose contents in both the stemwood and branchwood were higher than in the heartwood. However, the branchwood had a slightly higher cellulose content than the stem. This trend is similar to the one described by Magel (2000) and Taylor et al. (2002).

The average hemicellulose content recorded for stemwood and branchwood was 26.35% ± 1.19 and 26.55% ± 1.29, respectively (Table 1). Furthermore, the sapwood had more hemicellulose than the heartwood. This is also in agreement with the results of Magel (2000), which showed that heartwood had less hemicellulose than sapwood. The differences between the hemicellulose content in

Table 1. Lignin, cellulose and hemicellulose content in wood of stem and branches of *Terminalia catappa*. The contents are presented as mean values with standard deviations (in parentheses). Mean values with the same letters (a, a or b, b) are not significantly different, while different letters (a, b) indicate significant differences (P<0.05).

Preglednica 1. Vsebnost lignina, celuloze in hemiceluloz v lesu debla in vej *Terminalia catappa*. Vsebnosti so predstavljene kot povprečne vrednosti s standardnimi odkloni (v oklepajih). Srednje vrednosti z enakimi črkami (a, a ali b, b) niso statistično značilno različne, medtem ko različne črke (a, b) nakazujejo statistično značilne razlike (P<0,05).

Tree section	Chemical compound (%)	Content (%) (standard deviation)		
		Sapwood	Heartwood	Average
Stem	Lignin	21.45a (1.22)	24.95b (1.06)	23.20 (1.14)
	Cellulose	32.71a (1.18)	31.32b (1.24)	32.22 (1.21)
	Hemicellulose	28.23a (1.14)	24.47b (1.24)	26.35 (1.19)
Branch	Lignin	22.55a (1.14)	24.13b (1.02)	23.34 (1.08)
	Cellulose	33.43a (1.06)	31.14b (1.13)	33.10 (1.09)
	Hemicellulose	28.10a (1.02)	25.00b (1.56)	26.55 (1.29)

Table 2. Extractives (% per dry wood) in stem and branch wood of *Terminalia catappa*. The contents are presented as mean values with standard deviations (in parentheses).

Preglednica 2. Ekstraktivne snovi (% na suh les) v lesu debla in vej vrste *Terminalia catappa.* Vsebnosti so predstavljene kot povprečne vrednosti s standardnimi odkloni (v oklepajih).

Specie	Tree section	Tissue	Content of extractives (%)			
			Cold water	Hot water	Acetone	Ethanol
	Stem	Sapwood	9.09 (0.67)	7.43 (1.82)	1.95 (1.24)	2.93 (0.61)
		Heartwood	15.86 (2.01)	11.40 (1.78)	3.87 (0.69)	3.74 (0.43)
		Average	14.15 (1.84)	11.16 (1.63)	3.30 (0.84)	4.18 (0.68)
						8.19
	Branch	Sapwood	8.06 (1.86)	7.22 (1.64)	1.40 (0.52)	1.59 (0.24)
		Heartwood	12.34 (2.89)	11.87 (1.94)	2.80 (0.83)	2.78 (0.72)
		Average	11.75 (2.60)	10.85 (1.87)	2.29 (0.74)	2.54 (0.67)
						6.85

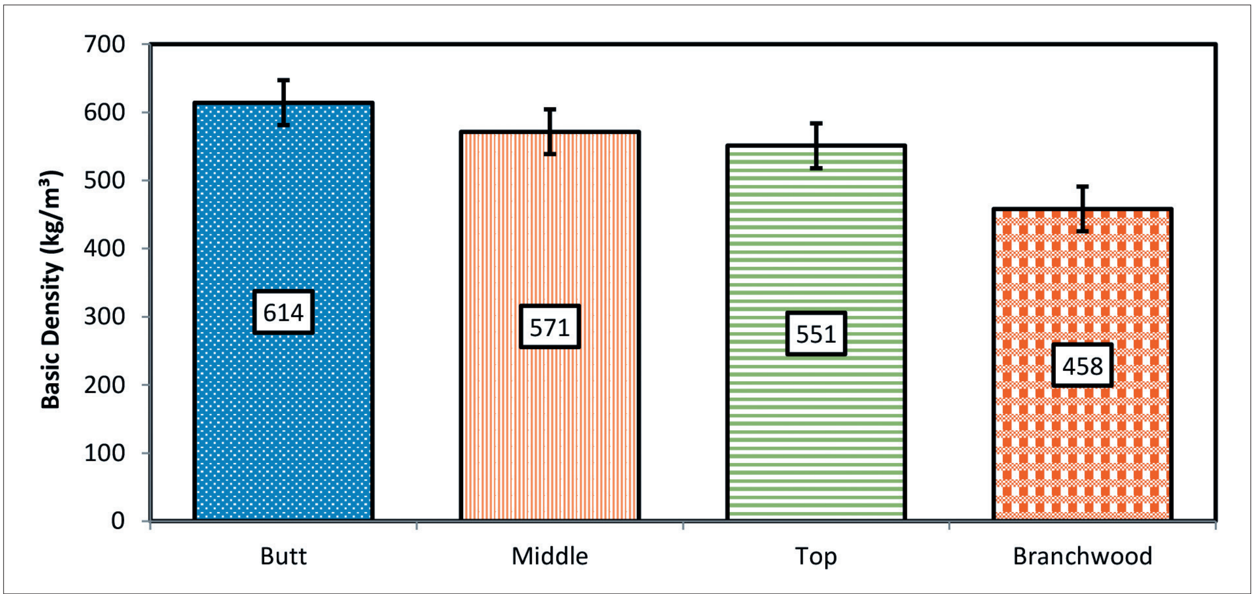

Figure 5. Average basic density of *Terminalia catappa* wood of the basal, middle and top part of the stem and in the branchwood. Error bars = standard deviation.
Slika 5. Povprečne vrednosti (in standardni odkloni) osnovne gostote lesa vrste *Terminalia catappa* v spodnjem, srednjem in zgornjem delu debla ter v vejah. Ročaji = standardni odklon.

Table 3. Basic density (means and standard deviations) of *Terminalia catappa* wood based on oven dry mass and maximum volume at the given moisture contents.
Preglednica 3. Srednje vrednosti in standardni odkloni za osnovno gostoto lesa (masa absolutno suhega lesa na maksimalni volumen pri danih vlažnostih) vrste *Terminalia catappa*.

Tree Sections	Position	Moisture Content (%)	Basic Density (kg/m³)
Butt	Sapwood	63.59± 4.71a	648.88±40.76a
	Heartwood	76.98±3.35b	579.25±53.18b
Middle	Sapwood	68.38±8.64c	581.87±46.39c
	Heartwood	82.80±6.79d	560.94±42.18d
Top	Sapwood	80.91±3.89e	572.88±65.88c
	Heartwood	88.76±11.59f	529.19±96.23d
Branchwood	Sapwood	98.88±8.31s	472.81±93.20e
	Heartwood	110.99±10.84t	443.56±72.43f

the sapwood and the heartwood of the stemwood were statistically significant (P>0.05) (Table 1). The hemicellulose content was also significantly lower in the heartwood (25.00%) than in the sapwood (28.10%) in the branchwood of *Terminalia catappa*.

Table 2 contains the percentage variation of extractives obtained by different less and more polar organic solvents for the stemwood and branchwood, and also the variation of extractives across the sapwood and the heartwood of *Terminalia catappa*. The stemwood had higher total extractive content than the branchwood. The stemwood and branchwood had extractive contents of 8.19% and 6.85%, respectively. The comparison of the extrac-

Table 4. ANOVA for moisture content and density of *Terminalia catappa* tree sections. Variability.
Tabela 4. Analiza variance (ANOVA test) za vrednosti vlažnosti in gostote lesa v deblu in vejah vrste *Terminalia catappa*.

Source	Df	Moisture Content			Basic Density	
		F-Value	Sig.	Var. (%)	F-Value	P-value
Tree sections (TS)	3	151.885	0001**	75	38.527	0.001**
Position (P)	1	93.107	0.001**	38	14.871	0.001**
TS × P	3	1.36	0.255ns	2.6	1.014	0.388ns

Note: ** = highly significant at p<0.01, * = significant at p<0.05, ns = not significant
Opomba: ** = stopnja statistične značilnosti visoka (p<0.01), * = pomembna (p<0.05), ns = razlike niso statistično značilne.

tion yields obtained with cold water, hot water, acetone and ethanol showed that the highest amounts of extractives were obtained with cold water. This was followed by the use of hot water, ethanol and acetone respectively. The amount of the extractives obtained by the acetone was the lowest. The extractive contents were also lower in the sapwood and higher in the heartwood (Table 2).

3.2 DENSITY OF WOOD
3.2 GOSTOTA LESA

The basic density of the wood of *Terminalia catappa* in the sapwood ranged from 473 to 649 kg/m³, while in the heartwood (HW) it ranged from 444 to 579 kg/m³. The average mean densities were the highest in the basal portion (614 kg/m³) while the branches had the lowest density of 458 kg/m³ (Table 3. and Figure 5).

The result of ANOVA (Table 4) indicates that at a 5% significance level, the tree sections and position significantly affect density. The results of Tukey's multiple comparison tests show that for the tree sections, the density differences are significant across the sections.

4 CONCLUSIONS
4 SKLEPI

We concluded that the cellulose and hemicellulose content were higher in the sapwood than in heartwood, and in the branchwood than in stemwood. However, the lignin and extractive content were higher in the heartwood than in sapwood, and in the stemwood than in branchwood.

The basic density of the sapwood ranged from 473 to 649 kg/m³, while in the heartwood from 444 to 579 kg/m³ being the highest in the butt portion (average 614 kg/m³) and the lowest in the branches (average 458 kg/m³).

The study addresses a gap in the literature by offering in-depth details about the basic density and chemical characteristics of *Terminalia catappa* wood, an alternate timber species. It adds to our knowledge of the properties of the wood by revealing new information, such as the fact that the sapwood and branchwood have higher cellulose and hemicellulose concentrations than the heartwood and stemwood. The study also emphasizes how *Terminalia catappa* has the potential to be a sustainable substitute for traditional wood species for structural applications. This will help in creating jobs and encouraging diversification in the wood sector. Overall, this study contributes to scientific research by offering useful information and guiding sustainable methods for using substitute wood species.

5 SUMMARY
5 POVZETEK

Prevelika odvisnost od tradicionalnih znanih lesnih vrst, kot so odum ali iroko (*Milicia excelsa*), ofram ali limba (*Terminalia superba*), wawa ali samba (*Triplochiton scleroxylon*), veliko povpraševanje po lesnih proizvodih ter visoke potrebe lesne industrije v Gani so privedle do prekomernega izkoriščanja omenjenih tradicionalnih in dobro znanih lesnih vrst. Zato številni raziskovalci iščejo druge alternativne materiale in rabe, kot so kmetijski odpadki za proizvodnjo različnih plošč. Potencialno zanimiva je tudi uporaba manj znanih in manj izkoriščenih lesnih vrst iz Gane, kot so wawabima

(*Sterculia rhinopetala*), akye (*Blighia sapida*), awiemfosemina (*Albizia ferruginea*) in bediwonua (*Canarium schweinfurthii*).

Med manj znanimi vrstami je tudi *Terminalia catappa* iz družine Combretaceae z lokalnimi imeni morski mandelj, ketapang ali tropski mandelj (angleško sea almond, ketapang, tropical almond). Vrsta uspeva predvsem v tropskih območjih Azije, Afrike in Avstralije. Oblikuje velika, do 40 m visoka drevesa s pokončnimi in vodoravnimi vejami. Listi so veliki, široki in jajčaste oblike. Zrela semena (oreščki) so užitna. *Terminalia catappa* je ena od manj znanih in manj uporabljanih lesnih vrst, ki je v Gani dobro zastopana z drevesi primerne velikosti za uporabo.

Na različnih delih dreves *Terminalia catappa* je bilo opravljenih več študij. Ben in drugi (2021) so na primer opravili biološke študije listov in ugotovili, da rastlina deluje zdravilno s protimikrobnimi, protiglivičnimi, protirakavimi, diaforetičnimi, protibakterijskimi, antidiabetičnimi, protiglivičnimi, hematološkimi in protitumorskimi aktivnostmi.

Podatki o lastnostih lesa so redki. Islam in sodelavci (2008) so preučevali les vrste *Terminalia catappa* in sicer nekatere fizikalne (gostota, vlažnost) in mehanske lastnosti (statični upogib, tlačna in natezna trdnost vzporedno z vlakni ter preskus izvleka vijakov) ter ugotovili, da je les srednje gost in se lahko uporablja kot konstrukcijski material, gorivo ali kot industrijska surovina. Quartey in drugi (2022) so navedli, da ima *Terminalia catappa* les srednje gostote s srednjo trdnostjo in e-modulom ter visoko strižno trdnostjo.

Nobena od navedenih študij ni preučevala kemijskih lastnosti *Terminalia catappa*, ki so bile glavni cilj te raziskave. Raziskana je bila tudi variabilnost gostote lesa različnih delov debla in vej.

Preučevali smo les treh dreves, vzorce smo odvzeli iz treh delov debla in iz ene velike veje. Študija je v prvem koraku zajemala pripravo materiala in zračno sušenje vzorcev lesa. Sledila je kemijska analiza vzorcev, pri čemer smo s standardnimi protokoli (TAPPI) vzorcem izmerili vsebnost celuloze, hemiceluloz, lignina in ekstraktivov. Osnovna gostota je bila določena v skladu s standardom ASTM D2395-07. Povprečna vsebnost lignina v vzorcih beljave in jedrovine debla je bila 21,45 % oziroma 24,95 %, značilno več lignina smo izmerili vzorcem jedrovine. Povprečna vsebnost celuloze v lesu je bila 32,22 % za vzorce debla in 33,10 % za vzorce vej. Povprečna vsebnost hemiceluloz je bila v lesu debla 26,35 % in v lesu vej 26,55 %. V beljavi debla in vej je bila vsebnost hemiceluloz značilno večja kot v jedrovini, kar potrjuje predhodne raziskave.

S pričujočo študijo smo ugotovili tudi to, da ima les debla vrste *Terminalia catappa* večjo vsebnost ekstraktivnih snovi kot les veje (8,19 % in 6,85 %). Kemijska analiza je pokazala, da smo največ ekstraktivov pridobili z ekstrakcijo s hladno vodo, manj z uporabo vroče vode in etanola, najmanj ekstraktivov pa se je iz lesa ekstrahiralo z acetonom. Vsebnost ekstraktivov je bila v beljavi značilno nižja kot v jedrovini.

Predstavljeni so tudi rezultati o variabilnosti osnovne gostote lesa vrste *Terminalia catappa*. Osnovna gostota beljave je bila od 473 do 649 kg/m³, jedrovine pa od 444 do 579 kg/m³, pri čemer je bila najvišja v spodnjem delu debla (srednja vrednost 614 kg/m³), najnižja pa v vejah (srednja vrednost 458 kg/m³). Vrednosti osnovne gostote les uvrščajo v razred nizke do srednje gostote, ki je primeren za lahke notranje konstrukcije in širok nabor drugih izdelkov.

Rezultati študije dopolnjujejo objavljene podatke o gostoti lesa ter povsem nova spoznanja o kemijskih lastnostih lesa *Terminalia catappa*. Novost predstavlja tudi ugotovitev, da je v primerjavi z jedrovino debla in vej višja vsebnost celuloze in hemiceluloz značilna za beljavo debla in vej.

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PHYSICAL AND MECHANICAL PROPERTIES OF WOOD OF PLANTATION GROWN *Albizia lebbeck* IN THE SAVANNAH ECOLOGICAL ZONE, GHANA

FIZIKALNE IN MEHANSKE LASTNOSTI LESA VRSTE *Albizia lebbeck* S PLANTAŽ V GANI

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Abstract / Izvleček

Abstract: The increasing scarcity of major commercial tropical hardwood species has necessitated the utilization of plantation grown exotic timber species as a potential means of maintaining Ghana's foundation of timber resources. To better consider *Albizia lebbeck* as a substitute for wood species which are being seriously over-exploited to the point of commercial extinction, its wood properties were characterized to expatiate its utilization potentials. Three mature plantation grown *Albizia lebbeck* trees with diameters 45-50 cm at breast height were purposively selected and sampled at four stem height levels of tree height. The samples were sawn into the required sizes in accordance with the British standard, BS 373 (1957) for testing. The heartwood and sapwood proportions were evaluated and the samples were examined for hardness, bending strength (MOE and MOR), compression strength parallel to grain, shear strength parallel to grain, and air-dry density. All trees had a significantly higher heartwood than sapwood percentage. The air-dry density values at 12% MC were 868 kg/m³, 806 kg/m³, 695 kg/m³ and 564 kg/m³ for four sections of the stem (heights 0-25%, 26-50%, 51-75% and 76-100%). In general, the plantation grown *Albizia lebbeck* exhibited favourable strength values, suggesting that it is endowed with adequate properties for being an alternative species to supply the wood industry.

Keywords: *Albizia lebbeck*, lesser-known timber species, plantation, heartwood, sapwood, wood density, modulus of rupture, modulus of elasticity

Izvleček: Zaradi naraščajočega pomanjkanja lesa tradicionalnih tropskih listavcev morajo v Gani vse bolj uporabljati les eksotičnih lesnih vrst. Ta prihaja s plantaž, kar pripomore tudi k ohranjanju tradicionalnih gozdnih virov. Cilj prispevka je raziskati lastnosti lesa vrste *Albizia lebbeck* in odgovoriti, ali bi les lahko uporabili kot nadomestek za nekatere tradicionalne lesne vrste. V ta namen so bila izbrana tri odrasla drevesa *Albizia lebbeck* s premerom 45–50 cm v prsni višini, vzorce lesa pa so odvzeli na štirih nivojih debla. Vzorci so bili razžagani na zahtevane dimenzije v skladu z britanskim standardom BS 373 (1957). Ocenjen je bil delež jedrovine in beljave, nato pa je bila raziskana trdota, upogibna, tlačna in strižna trdnost ter gostota zračno suhega lesa. Pri vseh drevesih je bil delež jedrovine znatno višji od deleža beljave. Vrednosti gostote na štirih nivojih po višini debla (0–25 %, 26–50 %, 51–75 % in 76–100 % višine) pa so bile 868 kg/m³, 806 kg/m³, 695 kg/m³ in 564 kg/m³. Na splošno so bile trdnostne lastnosti lesa vrste *Albizia lebbeck* s plantaže ugodne, kar nakazuje, da ima les primerne lastnosti, da bi ga lahko uporabili za potrebe lesne industrije in za širšo uporabo.

Ključne besede: *Albizia lebbeck*, manj znane lesne vrste, plantaže, jedrovina, beljava, gostota lesa, upogibna trdnost, modul elastičnosti

1 INTRODUCTION

1 UVOD

Due to unsustainable forest extraction, high-value hardwoods continue to become scarcer worldwide. The high level of global deforestation has several complicated and insufficiently un-

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derstood immediate consequences (Anon, 2012; Opuni-Frimpong et al., 2017; Owoyemi et al., 2017). It is known that the indiscriminate exploitation of forests, large-scale destruction of tree habitats, and adverse effects on populations are among the factors which have caused a number of timber species to disappear from forests (Amoah et al., 2015). Over reliance on the traditional timber species in Ghana has also led to their extinction in forests (Amoah et al., 2012). This has therefore put pressure on Ghana's forests, which are limited in extent with a total land area of about 239,000 km² and a general deforestation rate pegged at 65,000 hectares per annum (Husseini et al., 2020). The forest cover of Ghana is about 0.96 million hectares (42%) of the land area, out of which open forests cover about 0.8 million hectares, while closed forests cover 0.16 million hectares (Ghana Statistical Service, 2021). As such, the timber species such as Khaya spp. (mahogany), *Milicia excelsa* (iroko, odum), *Entandrophragma cylindricum* (sapelli, sapale), *Nesogordonia papaverifera* (kotibe, danta), *Terminalia superba* (limba, afram), and *Turreathus africanus* (avodire) for which Ghana is known in the international markets are becoming very scarce (Ntiamoa-Baidu et al., 2001).

Establishing plantations has been implemented to lessen the over exploitation of commercial timber species and help to restore degraded areas in Ghana (Agyeman et al., 2010). Both afforestation and plantation programmes utilizing plantation wood species have attracted a lot of attention, with the aim of balancing the current tropical timber markets and reducing the excessive utilization of the forests, (Bosu et al., 2006). The creation of plantation forests by planting exotic timber species would have numerous advantages, such as substituting natural forests for timber supply, restoring landscapes that have been damaged by deforestation, and offering ecological benefits, like sequestering carbon dioxide to lessen global warming (Onilude et al., 2020). As a result, it is acknowledged that forest plantations are important for their conservation value, for restoring areas that have been damaged, and for easing the burden of extraction on currently existing forests. As a result of all this, plantation forests are now widely regarded as a component of the conservation triangle, which also includes high-yielding plantations, regulated wild forests, and ecological reserves. In tropical Africa, exotic timber species which are not native in Ghana are mostly cultivated as part of agroforestry initiatives aimed at minimizing soil erosion, managing runoff to prevent desertification, and restoring severely damaged areas (Ogunwusi, 2002). Additionally, they aid in the manufacture of sawn timber, firewood, and, occasionally, pulp and paper (Hooper et al., 2005).

Since lumber is one of Ghana's most easily accessible resources, forest plantations have been of interest since the 1920s (Foli et al., 2009; Odoom, 2002). At the time, planting mostly native species in the high forest zone (HFZ) was the typical practice. The few exotic species that were grown in the HFZ were primarily brought in for mining purposes, as well as to provide fuelwood for boilers used to generate electricity and near densely populated areas (Nichols et al., 2006). Starting from 1951, a lot of exotic species were planted in the Savannah Zone (SZ) and Dry Semi-Deciduous Forest Zone (DFSZ) in order to offer fuelwood, poles, and lumber alternatives (Amoah et al., 2012; FAO, 2002). Consequently, plantations of hardwoods in the SZ's northern region are projected to span 2.553 hectares and are mainly used for the generation of fuelwood and the preservation of the environment (Odoom, 2002). The nation's natural forest is one of its many abundant resources (Opuni-Frimpong et al., 2004; Nichols et al., 2006), and it provided the nation's distinct climate and environmental conditions up until their recent overexploitation.

The increasing market demand for tropical hardwoods both locally and internationally is overwhelming. As such, the amount of wood that may be supplied for the lumber industry without endangering the forests exceeds the maximum capacity of Ghanaian sawmills (Appiah, 2003; Hooper et al., 2005). It is therefore imperative that the planting and use of plantation grown exotic timber species should be adopted on a large scale, if it is intended to replenish the depleting forest resources and as well as reduce the urgent demands on the remaining known species in the forest. As such, the current thinking is that industry players in the wood sector must consider the commercial value of the lesser used exotic species to minimize the high dependence on the commercial timber species. This is possible by obtaining the full utilization of the lesser-known timber species to substitute for the limited known tropical hardwoods that remain in the forest, and which are gradually becoming extinct.

The main motives for encouraging forest plantations in the nation are to lessen the strain on the natural forests while adding to their conservation, as well as making sure the nation can satisfy the demand for forest products from its expanding population (Oteng-Amoako, 2006). As such, Ghana's forest plantation initiatives have long been biased toward the establishment of exotic monoculture plantations (Opuni-Frimpong et al., 2008). Indeed, some two decades ago Odoom (2002) asserted that the majority of plantations now in existence in tropical nations, including Ghana, were dominated by exotic species plantations. The inclination towards foreign timber species may stem mostly from their rapid growth and relative lack of pests and diseases, as well as better fire resistance, than the numerous native species (Bobby et al., 2012). Furthermore, a greater variety of options are provided by foreign species because their silviculture is typically better understood than that of native species. Exotic timber species are thus the preferred planting stock, owing to their rapid growth and immediate economic return (Berger, 2006). It has therefore been proposed that the harvesting of abundant but lesser-known/used plantation grown exotic timber species needs to be gradually encouraged and increased in the country. Accordingly, plantation grown exotic species represent over 45% of the existing plantations in Ghana (Nanaag, 2012). Moreover, there are over 500 lesser-known species of timber size in the forests of Ghana which have never been used commercially (Oteng-Amoako, 2006). However, since the properties of plantation timbers are different from those of naturally grown ones, there is a need to investigate their properties and variability (Gorišek et al., 2018), as the present lack of reliable information makes predictions about their structural application hazardous and liable to gross errors. To address this gap in knowledge, the aim of this study is to assess selected physical and mechanical properties of a plantation grown *Albizia lebbeck* (L.) Benth, from the Savannah ecological zone from the Tamale fuel wood plantation reserve which lies between latitudes 9° 16 and 9° 34 north and longitudes 0° 36 and 0° 57 west in Ghana.

Albizia lebbeck, belongs to the family Fabaceae. It is a fast growing medium-sized, multipurpose deciduous tree species with a spreading umbrella-shaped crown of thin foliage and finely fissured, greyish-brown bark. On good sites, it can attain an average maximum height of about 18 to 30 m, and 50 to 80 cm diameter at breast height. The tree grows best on moist, and well-drained soils (Tiwari et al., 2020). The fragrant, cream-colored flowers develop on lateral stalks in rounded clusters about 5 to 7.5 cm across the many threadlike, spreading, whitish-to-yellow stamens tipped with light green, borne at the ends of lateral stalks 4 to 10 cm long. The fruits, flattened pods 10 to 20 cm long and 2.5 to 3.8 cm broad, are produced in large numbers and each contains several seeds. Immature pods are green, turning straw-colored on maturity, usually 6 to 8 months after flowering. Seeds are small, oblong, approximately 9 by 7 mm long and broad, compressed, and light brown in color. The leaves, seeds, bark and roots are all used for traditional medicine (Balkrishna et al., 2022). It was introduced as an ornamental and plantation tree throughout the tropics and northern subtropics (Inside Wood, 2024).

2 MATERIALS AND METHODS

2 MATERIALI IN METODE

2.1 SAMPLE PREPARATION

2.1 PRIPRAVA VZORCEV

Three (3) mature plantation grown *Albizia lebbeck* trees were purposively sampled from the Savannah ecological zone from the Tamale plantation reserve in Ghana. The age of the plantation *Albizia lebbeck* trees was about 45 years. Trees with similar diameters (45-50 cm) at breast height (1.3 m from the ground level) were felled and the merchantable length of the clear bole of each tree was measured and divided into four parts of the same size (0-25%, 26-50%, 51-75% and 76-100%). A stem sectional disc approximately 7.5 cm in thickness was cut at each end of the divided sections for the determination of the heartwood and sapwood proportions, and air-dry density at 12% moisture content.

An experimental study in the laboratory was employed to test the material properties. The wood specimens were prepared at the Tamale Technical University Wood Technology Workshop and every

Figure 1. *Albizia lebbeck* trees used for the study from Savannah ecological zone of Ghana.
Slika 1. Drevesa vrste *Albizia lebbeck*, uporabljena za študijo, z ekološkega območja Savannah v Gani.

test was conducted at the Council for Scientific and Industrial Research's (CSIR) of the Forestry Research Institute of Ghana (FORIG) at the Timber Mechanics and Engineering Laboratory. The specimens have been produced following British Standard BS 373, which specifies the use of an Instron machine to test small clear specimens of timber for mechanical properties (MOE, MOR, compression parallel to grain, shear parallel to grain, and hardness) and density at 12% MC. To ensure that the heartwood and sapwood portions of each billet were extracted, great care was taken in marking and sawing (Figure 1). The sawn planks were carefully chosen from visually verified defect-free areas to prepare the specimens. Following sawing, each wood sample was further ripped into the appropriate sizes for testing, and the boards underwent additional planning.

2.2 HEARTWOOD AND SAPWOOD PROPORTIONS
2.2 RAZMERJE JEDROVINE IN BELJAVE

To determine the heartwood and sapwood proportions, lines were drawn on the surface across the disc (South, South-East, East, North-East, North, North-West, West and South-West) as a reference point for the measurements to follow. A pencil dot was then marked directly on the line of each heartwood and sapwood borderline as shown in Figure 2. With the aid of a microscope, the borderline was determined on the basis of the natural color difference between the heartwood and sapwood. Each disc's diameters (heartwood and sapwood) were carefully identified and linear measurements were taken to the nearest ± 0.001 mm using a digital caliper, steel ruler and a tape measure in order to determine the heartwood and sapwood proportions as follows:

$$Total\ Disc\ Surface\ Area = \pi R^2 \quad (1)$$

Where

$$\pi = 3.142$$

$$R = \frac{R1 + R2 + R3 + R4 + R5 + R6 + R7 + R8}{8} \quad (2)$$

$$Heartwood\ Surface\ Area = \pi r^2$$

Where

$$r = \frac{r1+r2+r3+r4+r5+r6+r7+r8}{8}$$

$$Therefore;\ Sapwood\ Area = \pi \left(R^2 - r^2\right) \quad (3)$$

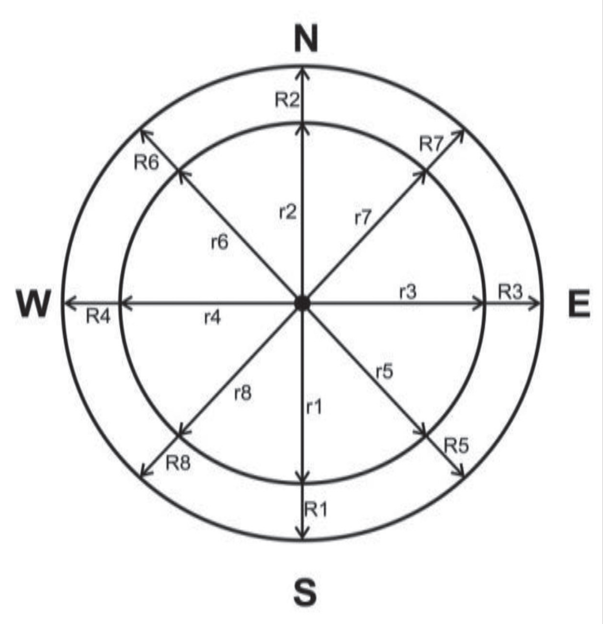

Figure 2. Lines drawn across disc surface for the measurement of the heartwood and sapwood portions.

Slika 2. Črte, narisane na prečno površino diska za merjenje deležev jedrovine in beljave.

2.3 PHYSICAL PROPERTIES OF *Albizia lebbeck* WOOD

2.3 FIZIKALNE LASTNOSTI LESA VRSTE *Albizia lebbeck*

2.3.1 Moisture Content (MC)

2.3.1 Vlažnost lesa (MC)

The green specimens that were obtained from all merchantable parts of the stems (0-25%, 26-50%, 51-75%, and 76-100%) were sawn into blocks 20 mm × 20 mm × 20 mm to determine the moisture content (MC) using the oven-dry method. The test specimens were instantly weighed using an electronic balance once they were prepared. After being oven-dried at 103 ± 2 °C, the specimens were cooled in desiccators and weighed again using an electronic scale. Until the weight remained constant, the process was repeated. The proportion of the wood's oven-dry weight was used for determining the moisture content (Panshin & de Zeeuw, 1980). To determine the moisture content, the original weights (W_1) and the oven-dry weight (W_2) were used to calculate the MC:

$$MC\% = \frac{W_1 - W_2}{W_2} x100 \quad (4)$$

Where MC = moisture content, W_1 = initial weight of sample (g), W_2 = oven-dry weight of samples (g).

2.3.2 Wood Density

2.3.2 Gostota lesa

The air-dry density for each sample (20 mm × 20 mm × 20 mm) was determined for parallel stem sections. The wood samples were air-dried in order to reach an appreciable percentage of moisture content before they were oven-dried at 103 ± 2 °C with intermittent weighing until a constant oven-dry mass (W_0) was obtained. After that, the specimens were conditioned for 120 days at 20 °C and 65% relative humidity to achieve a moisture content of roughly 12%. The specimens' masses and dimensions at 12% MC were utilized to determine the air-dry density:

$$\rho = \frac{m}{V} \quad (5)$$

Where ρ = air-dry density (kg/m³), m = air-dry mass (kg), V = volume of wood sample at 12% MC (m³).

2.4 MECHANICAL PROPERTIES

2.4 MEHANSKE LASTNOSTI

For the mechanical properties testing, the test specimens were prepared to the sizes and orientations required by the British Standard, BS 373. Samples were obtained from the tree sections (for each of the three trees). Having air-dried the specimens to an appreciable amount of moisture content they were conditioned to achieve the 12% moisture content and were stored for testing in a controlled chamber.

2.4.1 Modulus of Elasticity (MOE) and Modulus of Rupture (MOR)
2.4.1 Modul elastičnosti (MOE) in upogibna trdnost (MOR)

The three-point bending (central loading) system on an Instron Universal Testing Machine was utilized to perform the static bending tests (modulus of elasticity and modulus of rupture). The machine applied the loading automatically at a rate of 6.5 mm/min. The machine recorded the applied load and related deflection every 0.1 N intervals. The test piece was loaded at this speed until failure occurred. The maximum load at failure as well as the maximum load at the limit of proportionality was recorded by the computer component of the Instron Universal Testing Machine with reference to the outer points of loading. The duration of the test was 90 ± 30 seconds.

The modulus of elasticity, E, is computed as:

$$E = \frac{P_1 L^1}{4\Delta_1 A^2} \tag{6}$$

Where E = Young's modulus, i.e. modulus of elasticity (N/mm²), P_1 = load applied at the limit of proportionality (N), A = area of cross-section of beam normal to direction of load (mm²), Δ_1 = deflection at mid-length at limit of proportionality (mm), L = distance between supports (mm).

The highest load a wood sample can withstand before breaking is known as the modulus of rupture. A test approach identical to that described for MOE was employed to determine the MOR.

The modulus of rupture R, is calculated as:

$$R = \frac{3PL}{2bd^2} \tag{7}$$

Where R = modulus of rupture (N/mm²), P = maximum load applied at the midpoint of the sample (N), L = distance between supports (mm), b = breadth of test piece (mm), d = depth of the test sample (mm).

2.4.2 Compression Parallel to Grain
2.4.2 Tlačna trdnost vzporedno z vlakni

The parallel to longitudinal grain method (BS 373, 1957) was used to determine the resistance to compression. The sample sizes were divided into 2 cm × 2 cm x 6 cm sections using the 2 cm standard. Every specimen was examined to confirm that the testing apparatus was built of the appropriate materials and that the rectangular test piece was parallel, smooth, and normal to the axis. Throughout the whole test duration, the plates that held the test component were parallel to one another. To ensure that correct findings were produced, several checks were carried out. In compliance with BS 373, a total of 240 samples were tested using the Instron Universal Testing Machine. The duration of the test was 90 ± 30 seconds. This formula is used to calculate the compressive stress at maximum load:

$$C = \frac{P}{A} \tag{8}$$

Where C = compressive stress at maximum load (N/mm²), P = maximum load (N), A = cross sectional area of sample (mm²).

2.4.3 Shear Parallel to Grain
2.4.3 Strig vzporedno z vlakni

BS 373 (1957) was followed in the conducting of the test, with the standard specifying that the sample sizes were 5 cm x 5 cm x 5 cm. Two hundred and forty (240) samples of each billet's sapwood and heartwood were examined using the 100 kN load cell capacity of the Instron Universal Testing Machine. The crosshead moved at a steady pace of 0.635 mm/min as the load was applied. The grain's longitudinal direction and the shearing direction were parallel. The item was subjected to the load until it broke. The Instron Universal Testing Machine automatically documented the load at which failure occurred. The duration of the test was 90 ± 30 seconds. Shear parallel to the grain (V) is computed as follows:

$$S = \frac{P}{A} \tag{9}$$

Where S = shear (N/mm²), P = maximum load (N), A = area in shear (mm²).

2.4.4 Janka Hardness
2.4.4 Trdota po Janki

The BS 373 (1957) was followed while conducting the test. The specimen was chopped tangentially and radially to measure 5 cm x 5 cm x 15 cm for the hardness test. A total of 240 sapwood and heartwood samples were subjected to a hardness test fixture on the Instron Universal Testing Machine. The fixture consists of an 11.3 ± 2.5 mm diameter steel ball at one end of a steel bar. The hemispherical end of the steel bar (steel ball) enters the test piece when a load is applied. The Instron machine automatically records the failure load as the amount of force required to drive the steel ball's hemispherical end into the test piece to a depth of 5.6 mm, i.e. equal to the steel ball's radius. The determined maximum force required to indent the steel ball halfway into the wood was used to determine the Janka hardness. Merely the tangential and radial surfaces were determined. The radial and tangential surfaces that most closely resembled the actual radial and tangential directions of the grain were selected for testing.

2.4.5 Data Analysis
2.4.5 Analiza podatkov

Analysis of Variance (ANOVA) was used to compare the results from the radial portions and to determine whether the differences found between the sapwood and heartwood were significant. The statistical tool used for the analyses was SigmaPlot version 14.0. Descriptive statistics consisting of means with standard deviations were presented for each tree section used for the study.

3 RESULTS AND DISCUSSION
3 REZULTATI IN RAZPRAVA

3.1 HEARTWOOD AND SAPWOOD PROPORTIONS
3.1 DELEŽ JEDROVINE IN BELJAVE

The mean percentages of heartwood and sapwood proportions were 74% (26%), 75% (25%) and 74% (26%) for trees 1, 2 and 3, respectively (Figure 3). The bottom portion of each tree recorded a greater percentage of heartwood and the heartwood portion of the stem decreased from the bottom to the top of the stem whereas the sapwood portion of the stem increased from the bottom to the top, which is consistent with Qadri and Mahmood (2005). Heartwood is more durable than sapwood and less subjected to attack by insects, stain and mould producing fungi (Elzaki et al., 2012). The heartwood is also coloured and therefore considered more decorative than the light coloured sapwood (Hassan et al., 2007; Taylor et al., 2002; Zia-Ul-Haq et al., 2013).

3.2 PHYSICAL PROPERTIES (DENSITY) OF *Albizia lebbeck* WOOD
3.2 FIZIKALNE LASTNOSTI LESA (GOSTOTA) VRSTE *Albizia lebbeck*

Air dry density at 12% moisture content (MC) of three plantation grown *Albizia lebbeck* trees, showed the following results at different levels in

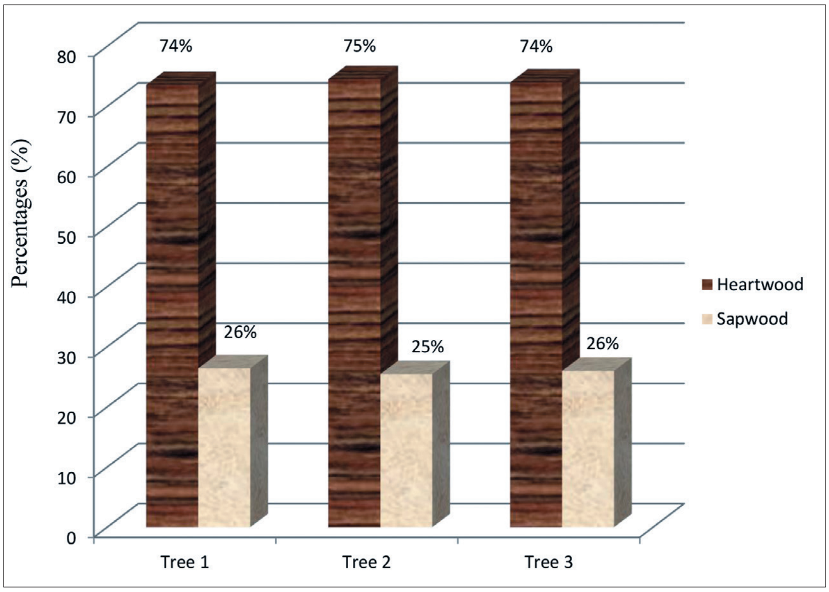

Figure 3. Average percentage (%) of heartwood and sapwood in the test trees.

Slika 3. Povprečni delež (%) jedrovine in beljave v testnih drevesih.

the stems: tree 1 recorded an average density of 842, 790, 659 and 573 kg/m³, tree 2 recorded 871, 788, 699 and 562, while tree 3 recorded an average density of 892, 841, 726 and 561 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively (Table 1).The mean difference between two close sections, for example 26-50% compared with 51-75%, was statistically insignificant. However, the mean difference for sections which are far apart, for example 0-25% and 76-100%, was statistically significant (Table 2 and 3). This trend was also reported by Moya and Ledezma (2003), as supported by the findings of Forest Products Laboratory (2010).

For radial variation, the heartwood displayed higher air-dry density than its corresponding sapwood portion. There was a significant difference in density between the heartwood and sapwood in all the trees studied. According to Onilude et al. (2020), wood generally increases in density during the transformation from sapwood to heartwood. The change in density is ascribed to deposition of extractives such as phenols and quinines, which enhances the durability of wood. Factors that might have had ab influence on the density values include the growth rate, plantation site, climate and geographical location (Sasmal et al., 2013; Wanneng et al., 2014), and as we showed the position in the

Table 1. Axial variation of air-dry density at 12% MC (kg/m³) of plantation grown *Albizia lebbeck.*
Preglednica 1. Aksialna variacija gostote zračno suhega lesa plantažno gojene vrste *Albizia lebbeck*.

Tree Section	Density at 12% MC (kg/m³)		
	Tree 1	Tree 2	Tree 3
0–25%	842.11 (±81.26)	871.41 (±77.66)	892.42 (±100.63)
26–50%	790.02 (±67.36)	788.08 (±64.00)	841.00 (±77.33)
51–75%	659.59 (±69.28)	699.85 (±63.57)	726.34 (±73.71)
76–100%	573.59 (±67.58)	562.40 (±54.64)	561.11 (±51.46)

Average value and standard deviation in parentheses.

Table 2. ANOVA for comparison of density between heartwood and sapwood portions. Number of replicates (N), standard deviation (Std. Dev), standard error of the mean (SEM), degrees of freedom (df), sum of squares (SS), mean square (MS), F-statistic (F), P-value (P).
Preglednica 2. Analiza variance (ANOVA) za primerjavo gostote med jedrovino in beljavo. Legenda: število ponovitev (N), standardni odklon (Std. Dev), standardna napaka povprečja (SEM), stopnje prostosti (df), vsota kvadratov (SS), srednji kvadrat (MS), F-statistika (F), P-vrednost (P).

Descriptive statistics						One Way RM ANOVA					
Tree portion	N	Missing	Mean	Std. Dev	SEM	Source of variance	df	SS	MS	F	P
T1 Heart	10	0	847.53	33.36	10.55	Between Subjects	9	14006.95	1556.33		
T2 Heart	10	0	845.95	31.91	10.09	Between portions	5	1922348.81	384469.76	834.71	<0.001
T3 Heart	10	0	840.21	34.90	11.04	Residual	45	20727.14	460.60		
T1 Sap	10	0	486.74	12.71	4.02	Total	59	1957082.89			
T2 Sap	10	0	482.68	14.07	4.45						
T3 Sap	10	0	490.48	12.29	3.89						

Table 3. Pairwise Multiple Comparison of density between heartwood sapwood. Degrees of freedom (df), t- value (t), P- value (P).
Preglednica 3. Večkratna primerjava parov povprečij gostote med jedrovino in beljavo. Legenda: stopnje prostosti (df), t-vrednost (t), P-vrednost (P).

Comparison	df	t	P	P<0.050
T1 HEARTWOOD vs. T2 SAPWOOD	364.852	38.014	<0.001	Yes
T2 HEARTWOOD vs. T2 SAPWOOD	363.275	37.849	<0.001	Yes
T1 HEARTWOOD vs. T1 SAPWOOD	360.793	37.591	<0.001	Yes
T2 HEARTWOOD vs. T1 SAPWOOD	359.216	37.426	<0.001	Yes
T3 HEARTWOOD vs. T2 SAPWOOD	357.529	37.251	<0.001	Yes
T1 HEARTWOOD vs. T3 SAPWOOD	357.056	37.201	<0.001	Yes
T2 HEARTWOOD vs. T3 SAPWOOD	355.479	37.037	<0.001	Yes
T3 HEARTWOOD vs. T1 SAPWOOD	353.470	36.828	<0.001	Yes
T3 HEARTWOOD vs. T3 SAPWOOD	349.733	36.438	<0.001	Yes
T3 SAPWOOD vs. T2 SAPWOOD	7.796	0.812	0.962	No
T1 HEARTWOOD vs. T3 HEARTWOOD	7.323	0.763	0.949	No
T2 HEARTWOOD vs. T3 HEARTWOOD	5.746	0.599	0.960	No
T1 SAPWOOD vs. T2 SAPWOOD	4.059	0.423	0.965	No
T3 SAPWOOD vs. T1 SAPWOOD	3.737	0.389	0.909	No
T1 HEARTWOOD vs. T2 HEARTWOOD	1.577	0.164	0.870	No

significance level = 0.05
stopnja značilnosti = 0,05

tree, too. These qualities can be compared to those of the most well-known timber species, including *Milicia excelsa* (odom), *Khaya* spp. (mahogany), *Cylicodiscus gabunensis* (denya), *Piptadeniastrum africanum* (dahoma), and *Aningeria* spp. (asanfena) that are in short supply in the timber markets.

3.3 MECHANICAL PROPERTIES
3.3 MEHANSKE LASTNOSTI

The average MOE of the wood of all the trees under study was 14356 N/mm², 14071 N/mm², 13322 N/mm², and 12367 N/mm² for all the tree sections 0-25%, 26-50%, 51-75% and 76-100%, respectively. Also, the MOR of all the trees had an average of 129 N/mm², 115 N/mm², 112 N/mm² and 101 N/mm² for the sections, respectively. Moreover, the average strength in compression parallel to grain of all the trees recorded 59 N/mm², 50 N/mm², 49 N/mm² and 46 N/mm² for the sections. Furthermore, shear parallel to grain for the trees under study recorded an average of 21 N/mm², 20 N/mm², 20 N/mm² and 17 N/mm² for the sections, respectively. Finally, the average hardness property obtained for all the trees recorded 11 kN, 11 kN, 9 kN and 7 kN for sections 0-25%, 26-50%, 51-75% and 76-100%, respectively (Table 4). Axial variation in the parameters strongly suggests that all the mechanical properties of all three trees decreased from the bottom portion of the trees to the top portion.

3.3.1 Modulus of Elasticity
3.3.1 Modul elastičnosti

Axial variation of all the plantation grown *Albizia lebbeck* strongly suggests that the MOE values reduce from the bottom portion of the tree to the top portion, with an average strength of 14356 N/mm², 14071 N/mm², 13322 N/mm², and 12367 N/mm², respectively, as shown in Table 3. However, the difference between the means was insignificant. This result confirms the assertion that the axial variation of some timber species decreases significantly along the bole height from the bottom portion to the top (Chulet et al., 2010). The analysis

Table 4. Means of mechanical properties of plantation grown *Albizia lebbeck.*
Preglednica 4. Mehanske lastnosti lesa vrste *Albizia lebbeck*, gojene v nasadih.

Mechanical Properties		Tree sections			
		0-25%	26-50%	51-75%	76-100%
MOE (N/mm²)	Tree 1	14688 (±1950.12)	14289 (±1885.69)	12212 (±1257.56)	11932 (±1465.17)
	Tree 2	15087 (±1230.09)	14746 (±1321.94)	14667 (±1285.54)	14022 (±1644.44)
	Tree 3	13292 (±2160.50)	13178 (±2529.27)	13087 (±1939.03)	11147 (±4024.22)
MOR (N/mm²)	Tree 1	128.65 (±12.62)	108.90 (±27.23)	108.43 (±16.68)	98.35 (±18.27)
	Tree 2	135.77 (±15.54)	121.06 (±14.38)	118.87 (±14.00)	115.28 (±18.87)
	Tree 3	122.70 (±24.44)	114.41 (±23.71)	108.46 (±21.04)	89.46 (±34.97)
Compression Parallel to grain (N/mm²)	Tree 1	66.63 (±9.66)	49.33 (±4.60)	47.60 (±5.55)	46.09 (±3.95)
	Tree 2	54.70 (±6.43)	52.69 (±5.66)	51.59 (±4.48)	45.94 (±4.65)
	Tree 3	54.23 (±5.43)	49.28 (±3.95)	47.65 (±2.25)	46.92 (±6.53)
Shear parallel to grain (N/mm²)	Tree 1	21.45 (±3.64)	20.02 (±7.24)	18.78 (±5.26)	15.18 (±3.91)
	Tree 2	21.45 (±2.59)	20.52 (±3.98)	20.49 (±2.76)	19.94 (±4.77)
	Tree 3	21.33 (±3.40)	20.80 (±2.42)	19.88 (±2.90)	16.88 (±3.88)
Janka Hardness (kN)	Tree 1	12.53 (±4.00)	12.31 (±8.30)	9.57 (±3.23)	7.07 (±2.01)
	Tree 2	8.70 (±2.15)	8.68 (±4.47)	6.12 (±1.96)	5.08 (±3.05)
	Tree 3	11.15 (±2.40)	10.83 (±2.42)	10.43 (±2.27)	8.18 (±1.00)

Average value and standard deviation in parentheses.
Povprečna vrednost in standardni odklon v oklepajih.

of variance (ANOVA) shows that there is an insignificant difference with regard to the modulus of elasticity between the tree sections within each individual tree of species.

3.3.2 Modulus of Rupture
3.3.2 Upogibna trdnost

In terms of axial variation, the species' bending strength, i.e. modulus of rupture, values typically decrease from the base to the apex of the tree. There was a noticeable marginal drop in MOR from the base to the top of the tree. This supports earlier claims (Ayarkwa et al., 2000; Uma et al., 2009) that strength qualities increase with decreasing moisture content. When comparing the heartwood's modulus of rupture sectionally, the mean difference amongst the trees was negligible. Most heavy construction species, including essa (104 MPa) and dahoma (109 MPa), compare favorably to the average mean values of MOR reported for *Albizia lebbeck* (129 N/mm², 115 N/mm², 112 N/

mm² and 101 N/mm²) for all three trees (Ayarkwa et al., 2000). *Albizia lebbeck* belongs to class S3, according to Bolza and Keating's (1972) classification.

3.3.3 Compression Parallel to Grain
3.3.3 Vzdolžna tlačna trdnost

The average compressive strength results obtained for *Albizia lebbeck* were 59 N/mm², 50 N/mm², 49 N/mm² and 46 N/mm² (Table 3, Table 4 and Table 5) for trees 1, 2 and 3, respectively, compares favourably with the values of most timber species used for heavy construction. Some of these include odum (*Milicia exelsa*) with a compressive strength of 52 MPa, ofram (*Terminalia superba*) with 33.80 MPa, iroko (*Chlorophora spp*) with 32.62 MPa, emeri (*Terminalia ivorensis*) with 35.00 MPa and dahoma (*Piptadeniastrum africanum*) with 23.00 MPa (Bosu et al., 2006; Forest Products Laboratory, 2010; Appiah-Kubi et al., 2012). Farmer (1972) classed the compressive strength parallel to the grain as follows: very low, low, medium, high, and very high when the strength values are under 20 MPa, 20–35 MPa, 35–55 MPa, 55–85 MPa, and over 85 MPa, in that order. As a result, the compressive strength of *Albizia lebbeck* is rated as medium in this classification.

3.3.4 Shear Strength Parallel to Grain
3.3.4 Vzdolžna strižna trdnost

The shear strength comparison indicated a significant mean difference between the heartwood and sapwood. This suggests that the radial variation strength of heartwood is greater with regard to resisting failure than that of the sapwood. Though the axial shear strength properties marginally decrease from the bottom portion to the top portion of the tree (21 N/mm², 20 N/mm², 20 N/mm² and 17 N/mm²), as depicted in Table 3, for all the trees. This trend confirms an earlier assertion by Hassan et al. (2007) and Sasmal et al. (2013). The strength values obtained for plantation grown *Albizia lebbeck* trees (19.72 N/mm²) compare favourably to those of most heavy construction species, including denya (*Cyclidiscus gabunensis*) at 11.10 MPa, dahoma (*Piptadeniastrum africanum*) at 9.60 MPa, and asanfena (*Aningeria altissima*) at 9.50 MPa, (Antwi et al., 2014).

3.3.5 Janka Hardness (Radial and Tangential)
3.3.5 Trdota po Janki (radialna in tangencialna)

There was no significant variation among the axial positions along the bole (0-25%, 26-50%, 51-75% and 76-100%) for hardness (Table 3, Table 4 and Table 5) for trees 1, 2 and 3, respectively. Evidently, these results demonstrate the ability of the various parts of all the trees of the plantation grown *Albizia lebbeck* to resist indentation. The resistance of *Albizia lebbeck* to indentation. i.e. Janka hardness, was relatively high (9.22 kN) for all the trees and it can be classified as a class IV hardwood, and thus used for high-class furniture production.

4 CONCLUSIONS
4 SKLEPI

The examination of the plantation grown timber species *Albizia lebbeck*, exotic in Ghana, has provided useful information in terms of the full utilization potential of this species as a good possible substitute for the limited known tropical hardwoods with similar properties, which are now facing extinction. Based on the findings of this study, the following conclusions were made. The heartwood and sapwood proportions (74%, 26%) of the plantation grown *Albizia lebbeck* varied considerably and statistically significantly in all the trees studied. The studied trees with a diameter of 40-50 cm generally had a greater percentage of heartwood than sapwood, suggesting that enough heartwood can be obtained from the stems for furniture and structural utilization. Heartwood is desired for furniture and other engineering purposes in the tropical zones where biodegradation by organisms is common. However, the sapwood of some species of timber could perform equally well when properly treated.

It was also observed that the plantation grown *Albizia lebbeck* species exhibited a mean density of 734 kg/m³ for all the trees under study. This reveals that *Albizia lebbeck* has the potential required by the furniture and construction industries to serve as a substitute for the rarer timber species. The mean density found in the present study is comparable to that reported for other timbers, such as *Celtis mildbraedii*, *Celtis zenkeri, Petersia africana* (essia), and *Nesogordonia papaverifera* (danta), which have densities of 781 kg/m³, 743 kg/m³, 738 kg/m³ and 712 kg/m³, respectively, and which are mostly used in the Ghanaian furniture and construction industries (Ofori et al., 2009).

In terms of the mechanical properties, the mean values for the modulus of elasticity (13528 N/mm²), modulus of rupture (114 N/mm²), maximum compressive strength parallel to grain (51 N/mm²), shear parallel to grain (19 N/mm²), and hardness (9 kN) varied significantly along the sampling height. Generally, all the mean values decreased along the tree height from the bottom to the top portion. The results showed that the MOE and MOR values were high and compared favorably with those of other commercial tree species, which confirmed the suitability of the plantation grown *Albizia lebbeck* species for various furniture and construction work.

Moreover, the compressive strength, resistance to shear and hardness values of *Albizia lebbeck* mean this wood has relatively high resistance to deformation and indentation, and there is always a strong correlation between wood hardness and strength. It can therefore be concluded that the plantation grown *Albizia lebbeck* species could be used for medium to heavy timber structures. The values recorded for the mechanical properties of the wood species have validated its suitability for use in high-quality furniture products and other interior applications.

5 SUMMARY

5 POVZETEK

V nasadih na ekološkem območju Savannah v Gani gojijo več eksotičnih lesnih vrst, za katere imamo malo informacij o lastnostih njihovega lesa. Znano je, da je trenutno že veliko dreves na plantažah zrelih za posek, a jih še vedno ne sekajo za komercialne namene. Medtem beležijo v Gani vse večje pomanjkanje lesa glavnih znanih komercialnih tropskih listavcev, zlasti tistih z gostejšim lesom. To spodbuja potrebo po uporabi lesa eksotičnih listavcev s plantaž, kar bi lahko delno zadostilo potrebam države po lesu. Med potencialno zanimivimi drevesnimi vrstami je *Albizia lebbeck*, ki bi lahko nadomestila nekatere bolj znane komercialne lesne vrste. Zato moramo bolje poznati lastnosti lesa te vrste in možnosti njegove uporabe. Namen te študije je bil določiti nekatere fizikalno-mehanske lastnosti lesa vrste *Albizia lebbeck* s plantaže na ekološkem območju Savannah, Tamale, v Gani. Specifični cilji raziskave so bili ovrednotiti deleže jedrovine in beljave in določiti nekatere fizikalne lastnosti (gostoto zračno suhega lesa) ter mehanske lastnosti (vzdolžna tlačna trdnost, vzdolžna strižna trdnost, trdota po Janki, upogibna trdnost in modul elastičnosti) in njihovo variabilnost vzdolž debla.

Izbrana so bila tri zrela drevesa vrste *Albizia lebbeck* s premeri od 45 do 50 cm v prsni višini (1,3 m). Drevesa so bila posekana in izmerjene so bile tehnične dolžine hlodov od baze drevesa do nivoja krošnje. Iz posameznih debel so bili izžagani hlodiči za raziskave na štirih nivojih glede na višino v drevesu (0–25 %, 26–50 %, 51–75 % in 76–100 % višine). Vzorci za določanje fizikalnih in mehanskih lastnosti so bili razžagani na zahtevane velikosti v skladu z britanskim standardom BS 373 (1957) za testiranje majhnih čistih vzorcev lesa. Označevanje in žaganje je bilo opravljeno tako, da so pridobili vzorce beljave in jedrovine iz vsakega segmenta raziskanih dreves. Za pripravo vzorcev so bile izbrane deske brez napak kot so grče, odklon vlaken in poškodbe, ki jih povzročajo biološki škodljivci ter abiotski dejavniki. Po žaganju smo deske še dodatno skobljali in skrbno pregledali z vidika morebitnih napak. Po sušenju do zračne suhosti so bili vzorci lesa izdelani v delavnici za lesno tehnologijo Tehniške univerze Tamale (Tamale Technical University Wood Technology Workshop). Vlažnost lesa pri zračni suhosti in v absolutno suhem stanju ter gostoto lesa smo določili v Laboratoriju za gradbeništvo in les (Construction and Wood Laboratory of the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Kumasi, Ghana). Vsi ostali testi so bili opravljeni v Laboratoriju za lesno mehaniko in inženiring Inštituta za gozdarske raziskave Gane (FORIG), Sveta za znanstvene in industrijske raziskave (CSIR) (Timber Mechanics and Engineering Laboratory, of the Forestry Research Institute of Ghana (FORIG) of Council for Scientific and Industrial Research (CSIR)).

Približno 7,5 cm debeli koluti s štirih nivojev v deblu posameznega drevesa so bili uporabljeni za oceno deleža jedrovine in beljave. Izmerjeni so bili premeri kolutov in premeri delov z jedrovino vzdolž več radijev za izračun deležev jedrovine in beljave. Upogibna trdnost (MOR) in modul elastičnosti (MOE), vzdolžna tlačna in strižna trdnost ter trdota

so bili določeni za zračno suh les, pri pribl. 12 % lesni vlažnosti.

Rezultati so pokazali, da ima *Albizia lebbeck* danih premerov višji delež jedrovine (74,04 %) kot beljave (25,96 %). Les je dokaj gost in ima gostoto zračno suhega lesa 869 kg/m³, 806 kg/m³, 695 kg/m³ in 565 kg/m³ na nivojih debla 0–25 %, 26–50 %, 51–75 % oziroma 76–100 % aksialne višine (preglednica 1). Na splošno je *Albizia lebbeck* imela dobre trdnostne lastnosti (Preglednica 4), kar kaže na to, da bi jo lahko uporabili kot alternativno vrsto za oskrbo lesne industrije. Očitno lahko plantaže dreves vrste *Albizia lebbeck* izkoriščamo za pridobivanje kvalitetnih žagarskih sortimentov. Sicer je les jedrovine temno rjav, prepreden s temnimi in belimi odtenki, to daje jedrovini dober videz in dekorativno teksturo, kar je pomembno za rabo v notranjih prostorih in za izdelavo pohištva. Čeprav gostota lesa variira v aksialni smeri dreves, in od spodnjega do zgornjega dela drevesa upada, razlika povprečij gostote med testiranimi četrtinami delov debel ni bila značilna (t-test; p > 0,05). Srednje vrednosti mehanskih lastnosti so bile primerljive z vrednostmi lesnih vrst, kot so denia (*Cyclidiscus gabunensis*), dahoma (*Piptadeniastrum africanum*), asanfena (*Aningeria altissima*) in druge, ki jih uporabljajo v Gani za gradbene namene. Na splošno je bila trdota lesa vrste *Albizia lebbeck* razmeroma visoka, kar nakazuje, da je les uporaben za pohištvo in druge notranje konstrukcije.

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PRIMERNOST OSTANKOV MLETE KAVE ZA PROIZVODNJO PELETOV

SUITABILITY OF SPENT GROUND COFFEE FOR PELLET PRODUCTION

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Izvleček / Abstract

Izvleček: Za doseganje cilja evropske energetsko-podnebne politike, da do leta 2050 dosežemo podnebno nevtralnost s prehodom na obnovljive vire energije, je potrebno aktivirati različne razpoložljive obnovljive vire, vključno z biološkimi ostanki oz. odpadki. Eden od takih bioloških odpadkov, ki nastaja v velikih količinah in se večinoma nepredelan odlaga v okolje, so ostanki mlete kave. Ker ostanke mlete kave sestavljajo celuloza, hemiceluloza, lignin in proteini, predstavljajo velik potencial tudi kot biogorivo, ki lahko delno nadomesti lesno biomaso pri proizvodnji peletov. V raziskavi smo v laboratorijskih pogojih izdelali pelete iz ostankov mlete kave, ki smo jim dodali različne deleže (0 %, 25 %, 50 %, 75 %) žagovine. Izdelanim peletom smo določili lastnosti in jih glede na izmerjene vrednosti razvrstili v kakovostne razrede po standardu SIST EN ISO 17225-6:2021. Ugotovili smo, da imajo peleti z večjim deležem ostankov mlete kave višjo kurilno vrednost, večjo vsebnost pepela ter nižjo mehansko obstojnost. Peleti, izdelani iz ostankov mlete kave in dodatkom žagovine (50 % ali več), izkazujejo obetavne lastnosti kot vhodna surovina za proizvodnjo peletov.

Ključne besede: peleti, ostanki mlete kave, žagovina, biološki odpadki, kurilna vrednost, kakovost peletov

Abstract: In order to achieve the European energy and climate policy goal of climate neutrality by 2050, it is necessary to activate various available renewable energy sources, including biological residues or waste. One such biological waste, which is produced in large quantities and usually enters the environment unprocessed, is spent ground coffee. As spent ground coffee consist of cellulose, hemicellulose, lignin and proteins, it has great potential as a biofuel, and could partially replace wood biomass in the production of pellets. In our research, we have produced pellets under laboratory conditions from spent ground coffee to which we have added different proportions (0%, 25%, 50%, 75%) of sawdust. We determined the properties of the pellets and categorized them into quality classes based on the measured values according to the SIST EN ISO 17225-6:2021 standard. We found that pellets with a higher proportion of spent ground coffee residues have a higher calorific value, higher ash content and lower mechanical durability. Pellets made from spent ground coffee residues with the addition of sawdust (50% or more) show promising properties for use as a raw material for pellet production.

Keywords: pellets, spent coffee grounds, sawdust, bio waste, calorific value, pellets quality

1 UVOD

1 INTRODUCTION

Vse večja poraba energije, zaostreni pogoji za zagotavljanje zanesljivosti energetske oskrbe in tudi skrb za okolje v najširšem smislu zahtevajo vključevanje najrazličnejših virov energije. Z vidika varovanja okolja, trajnosti, krožnosti in gospodarnosti je potrebno aktivirati predvsem rabo najrazličnejših bioloških odpadnih materialov, ki v procesu predelave ali izrabe ostajajo kot ostanki ali odpadki in lahko v veliki meri nadomestijo rabo lesne biomase kot energenta (Castellano et al., 2015; Škorkov, 2018; García et al., 2019; Anžič, 2021). Lesni peleti so v zadnjih letih zelo pomembna oblika trdih biogoriv,

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namenjeni tako individualni rabi za pridobivanje toplotne energije kot tudi industrijski rabi za pridobivanje toplotne in električne energije (Döring, 2013; Obernberger & Thek, 2010). Iz tega razloga raba in posledično proizvodnja peletov konstantno narašča in se je v obdobju zadnjih desetih let na globalnem nivoju povečala za 2,6-krat. Tako je proizvodnja peletov v letu 2022 znašala 47,6 · 10^6 ton (v letu 2012 pa 18 · 10^6 ton) (FAO, 2023), pri čemer v EU porabimo skoraj polovico svetovne proizvodnje peletov. V letu 2022 je poraba peletov v EU znašala 24,2 · 10^6 ton, proizvodnja pa 24,5 · 10^6 ton (Timber-online, 2024). V prihodnjih letih se še vedno pričakuje rast porabe lesnih peletov, ki lahko učinkovito nadomeščajo rabo fosilnih goriv in s tem pozitivno vplivajo na zmanjševanje izpustov toplogrednih plinov. Lesni peleti so trenutno izdelani predvsem iz ostankov lesnopredelovalne industrije in gozdne proizvodnje (de Souza et al., 2021). S principa krožnosti pa imajo tudi druge učinkovitejše možnosti rabe (Zule et al., 2017; Čufar et al., 2017; Kropivšek et al., 2023; Kropivšek et al., 2024), pri čemer se dosega tudi višja dodana vrednost proizvoda.

Po poročanju Mednarodne agencije za energijo IEA (IEA, 2021) je v scenariju Net Zero (NZE) do leta 2050 predvideno, da bo več kot 60 % svetovne oskrbe z bioenergijo, ki je ocenjena na velikost 100 EJ, leta 2050 izviralo iz trajnostnih tokov odpadkov, ki ne zahtevajo namenske rabe zemljišč. To vključuje kmetijske ostanke, organske komunalne odpadke in ostanke iz gozdarstva in lesne industrije. Po scenariju NZE v letu 2050 ostanki iz predelave lesa in sečnje gozdov zagotavljajo zgolj 20 % bioenergije, pridobljene iz trajnostnih tokov odpadkov, kar pomeni manj kot polovico od trenutnih najboljših ocen celotnega tehničnega potenciala sektorja (IEA, 2021). Zato je potrebno najti načine za aktivacijo in učinkovito izrabo odpadnega biomateriala z uporabo naprednih novih in tudi že znanih in/ali prilagojenih tehnologij. S temi viri bi lahko v dobršni meri nadomestili rabo lesne biomase v energetske namene.

V Sloveniji letno nastane nekaj več kot 1 · 10^6 ton komunalnih odpadkov, kar v letu 2022 pomeni 496 kg na prebivalca, pri čemer predstavljajo ostanki mlete kave (v nadaljevanju kavni ostanki) 1,2 % (Anžič, 2021). V hierarhiji ravnanja z odpadki (GOV, 2024) ima recikliranje in ponovna uporaba odpadkov višjo prioriteto kot energetska izraba odpadkov, medtem ko ima odlaganje odpadkov najnižjo prioriteto. Kavni ostanek se večinoma odlaga v okolje brez kakršnekoli predelave, pri čemer ima to vpliv na prst in rast rastlin. Kavni ostanek vsebuje veliko ogljikovih hidratov, beljakovin, lipidov in bioaktivnih spojin, ki izboljšujejo kakovost tal s izboljšanjem fizikalno-kemijskih lastnosti tal in biološke rodovitnosti. Vendar pa kavni ostanek pri nizkih koncentracijah (1 %) v zemlji lahko zavira rast rastlin zaradi stimulacije mikrobne rasti talnih mikroorganizmov in posledično tekmovanja za talni dušik med mikroorganizmi in rastlinskimi koreninami, kot tudi zaradi prisotnosti fitotoksičnih spojin (npr. polifenolov) (Peraz-Burillo et al., 2022). Rešitev vidijo v vermikompostiranju (Peraz-Burillo et al., 2022).

Glede na dejstvo, da se kavni ostanki v obsegu 93 % še neobdelani odlagajo v okolje (Atabani et al., 2023), ostaja velik biomasni potencial z izredno pestro vsebnostjo različnih organskih spojin neizkoriščen. Atabani et al. (2023) podaja podrobno študijo poznanih rab kavnega ostanka za proizvodnjo peletov in njene kemijske sestave. Vsebnost posameznih komponent zavisi od vrste kave, načina predelave in priprave ter rokovanja z ostanki kave. Prevladuje celuloza (20–30 %), hemiceluloza (10–20 %) in lignin (10–20 %). Ostanki kave vsebujejo tudi 10–20 % lipidov (trigliceridov in maščobnih kislin), 10–15 % proteinov in manjše deleže mineralnih snovi, kofeina in taninov. Ta pestrost omogoča rabo ostankov kave v različne namene od proizvodnje biodizla, bioetanola, bioplina do uporabe v gradbeno-inženirske namene kot so npr. vključevanje v zvočno izolativni material (Nosek et al., 2019; Anžič, 2021; Colantoni et al., 2021; Atabani et al., 2023; Lee et al., 2023). Tudi elementarna sestava kavnega ostanka izkazuje velik potencial za rabo le-tega v energetske namene, saj v povprečju vsebuje več ogljika (vsebnost 46–71 %), vodika (vsebnost 6–9 %) in manj kisika kot številne vrste druge biomase (Atabani et al., 2023).

Kava velja za najpomembnejše kmetijsko trgovsko blago, saj se po obsegu trgovanja uvršča takoj za nafto. Največji proizvajalci kave so države Južne Amerike (Brazilija, Kolumbija) in jugovzhodne Azije (Vietnam). Svetovna proizvodnja kave je v letu 2022 znašala skoraj 10,3 · 10^6 ton in poraba 10,7 · 10^6 ton, pri čemer smo Evropejci z 31 % največji porabniki kave. Pri tem prevladujeta dve vrsti kavovca in sicer Arabica (60 % svetovne proizvodnje)

Slika 1. Faze predelave kave: (a) surova kava Arabica in Robusta, (b) vreča surove kave, (c) skladiščenje surove kave, (d) ohlajevanje pražene kave.

Figure 1. Stages of coffee processing: (a) raw Arabica and Robusta coffee, (b) bag of raw coffee, (c) storage of raw coffee (d) cooling of roasted coffee.

in Robusta (skoraj 40 % svetovne proizvodnje) in v majhnem obsegu še Liberica in Excelsa. Ocenjuje se, da letno nastane okrog 15 · 10^6 ton ostankov kave, ki se praviloma odlagajo na odlagališčih oz. ostane neizkoriščena. Količina ostankov kave je sicer odvisna od številnih dejavnikov (postopka priprave kave, granulacije kave …) in se giblje nekje med 65 % (Colantoni et al., 2021; Atabani et al., 2023) pa vse do 91 % (Lee et al., 2023), oziroma na 1 kg kave dobimo okrog 2 kg vlažnega ostanka kave. Kavni ostanek, ki vsebuje različne organske spojine, za svojo razgradnjo potrebuje veliko kisika in pri kompostiranju nastaja kompost z veliko vsebnostjo dušika. Pri neustreznem odlaganju kavnega ostanka v prevelikih količinah obstaja zaradi fermentacije ostanka tudi nevarnost samovžiga in tvorba velikih količin metana, ogljikovega dioksida ter neprijetnih vonjav. Neprimerno odlaganje kavnega ostanka v okolje lahko vodi v njegovo onesnaženje (Lee et al., 2023) in povzroča toksičnen vpliv na nekatere vodne organizme.

Po podatkih SiStat (SiStat, 2024 a) je Slovenija v letu 2023 skupno uvozila 22.100 ton kave (od tega s 75 % prevladuje nepražena kava), medtem ko je bil izvoz kave v obsegu 11.000 ton, iz česar lahko zaključimo, da smo v Sloveniji v letu 2023 popili 11.100 ton kave oziroma skoraj 5,3 kg na prebivalca (kavni nadomestki niso upoštevani). Tako lahko ocenimo, da je v letu 2023 nastalo med 6.600 ton in 10.000 ton kavnega ostanka.

Kava je ena izmed najbolj priljubljenih pijač zaradi raznolikega in aromatičnega okusa, ki ima zaradi kofeina zelo poživljajoč učinek. Kavo proizvajamo iz plodov kavovca (Coffea), ki spada v družino Rubiaceae. Najpomembnejši vrsti za pridelavo kave sta *Coffea arabica* (Arabica) in *Coffea canephora* (Robusta) (slika 1 a). Arabica predstavlja skoraj dve tretjinji svetovne pridelave kave in je cenjena po svojih bogatih okusih in aromah, medtem ko ima Robusta močnejši okus in večjo vsebnost kofeina in se pogosto uporablja v mešanicah espresso kave.

Postopek predelave kave obsega več faz in od njihove izvedbe je zelo odvisno, kakšen bo okus kave. Plodovom grma kavovca po ročnem obiranju najprej odstranijo ovoj, ki obdaja vsako zrno kave, zrna nato posušijo na zraku in sortirajo po kakovosti, velikosti in teži. Na ta način dobimo surovo kavo, ki se večinoma pakira v 60 kg vreče, ki so osnovna enota pri trgovanju s surovo kavo (slika 1 b, c). Surovo kavo nato pražijo, pri čemer so pogoji praženja (temperatura in trajanje praženja) ključnega pomena za okus in aromo kave. Temu sledi hlajenje pražene kave (slika 1 d). Nadaljnji postopki (mletje in pakiranje) so odvisni od načina priprave kave.

Po podatkih Gozdarskega inštituta Slovenije (GIS, 2023a) je v letu 2022 proizvodnja peletov pri nas znašala 164.000 ton, po podatkih SiStat-a (SiStat, 2024 b) smo uvozili 125.614 ton peletov in izvozili 164.679 ton. Stanje kakovosti lesnih peletov na slovenskem trgu periodično spremljajo na Gozdarskem inštitutu Slovenije v sodelovanju z Zvezo potrošnikov Slovenije in ugotavljajo, da se kakovost peletov na slovenskem tržišču izboljšuje, saj prevladujejo peleti najvišje kakovosti A1 (GIS, 2023b). Kot kaže ena zadnjih raziskav (Pirc Barčić et al., 2020), v kateri so s pomočjo ankete raziskovali trenutno stanje rabe peletov in predvidevanja njihove rabe za naslednje petletno obdobje, se v Sloveniji na lesno biomaso ogreva 43 % gospodinjstev, v naslednjih petih letih pa namerava preiti na pelete še dobra petina gospodinjstev. V proizvodnji peletov se danes največ uporablja les oziroma ostanki iz žagarske in lesnopredelovalne industrije (npr. sekanci, žagovina in drobni oblanci), saj je takšen les neoporečen in kemijsko neobdelan (Gornik Bučar et al., 2021). Za žagovino so značilni majhni delci, zato priprava surovine za nadaljnje peletiranje ni energetsko potratna. Praviloma je žagovina iz žagarskih obratov brez lubja (ali drugih nečistoč), kar omogoča proizvodnjo visokokakovostnih peletov.

Kakovost nelesnih peletov in mejne vrednosti posameznih kriterijev opredeljuje standard SIST EN ISO 17225-6:2021, po katerem razvrčamo pelete, izdelane iz zelnate, sadne in vodne biomase, ter njenih mešanic z lesno biomaso. Omenjeni standard sodi v serijo standardov SIST EN ISO 17225:2021, ki definirajo ključne parametre in njihove mejne vrednosti, ki jih nadziramo pri razvrščanju biogoriv v kakovostne razrede. Standardi v posameznih delih določajo kakovostne razrede trdih biogoriv in sicer peletov, sekancev, briketov, drv in nelesnih peletov in briketov. Mejne vrednosti posameznih lastnosti nelesnih peletov, ki jih opredeljuje standard SIST EN ISO 17225-6:2021, prikazuje preglednica 1.

Preglednica 1. Specifikacija peletov, izdelanih iz nelesne biomase po standardu SIST EN ISO 17225-6:2021.
Table 1. Specification of non-woody pellets according to the EN ISO 17225-6:2021.

	Mejna vrednost za kakovostni razred A	Mejna vrednost za kakovostni razred B
Vsebnost vode [%]	≤ 12	≤ 15
Mehanska obstojnost [%]	≥ 97,5	≥ 96
Gostota nasutja [kg/m³]	≥ 600	≥ 550
Vsebnost pepela [%]	≤ 6,0	≤ 10
Kurilna vrednost [MJ/kg]	≥ 14,5	≥ 14,5

2 MATERIALI IN METODE
2 MATERIALS AND METHODS
2.1 MATERIALI
2.1 MATERIALS

Za proizvodnjo smo uporabili kavne ostanke z vsebnostjo vode okoli 60 %, ki smo jih dobili v gostinskem lokalu, pri čemer je prevladovala kava vrste Arabica. Kavni ostanek je preostanek kave po ekstrakciji pri temperaturi nad 95 °C in povišanem tlaku.

Žagovino smo dobili iz žagarskega obrata, ki razžaguje svežo, lupljeno hlodovino iglavcev. Žagovina je imela vlažnost med 50 % in 60 %.

2.2 METODE
2.2 METHODS

Postopek izdelave peletov je potekal v več fazah, pri čemer smo najprej analizirali vhodno surovino (kavni ostanek in žagovino), pripravili ustrezne mešanice za peletiranje, izvedli postopek peletiranja in nato določili lastnosti izdelanih peletov.

2.2.1 Analiza vhodne surovine in priprava mešanice surovine
2.2.1 Analysis of incoming raw material and preparation of raw material mixture

Vhodni surovini (žagovini in kavni usedlini) smo določili začetno vlažnost, jo posušili in s sejalno analizo določili velikost delcev. Dostavljeni surovini smo določili začetno vlažnost skladno s standardom SIST EN ISO 18134-2:2017 s sušenjem pri temperaturi 103 °C do konstantne mase. Na osnovi dobljenih podatkov o vlažnosti smo vso surovino posušili v sušilni komori Memmert UFP 600. Za izdelavo peletov smo žagovino pomleli z mlinom Retsch SM200 prek sita z velikostjo delcev 4 mm. Iz posušene in zdrobljene surovine smo pripravili štiri mešanice z različnimi volumskimi razmerji kavnega ostanka in žagovine (preglednica 2). Nasutna go-

Preglednica 2. Surovinska sestava peletov (volumska razmerja).
Table 2. Raw material composition of pellets (volume ratios).

Oznaka	25 K	50 K	75 K	100 K
Kavni ostanek (delež %)	25	50	75	100
Žagovina (delež %)	75	50	25	0

stota žagovine z vsebnostjo vode 11,7 % je znašala 174,6 kg/m³, nasutna gostota ostanka kave z vsebnostjo vode 1,7 % pa 321,6 kg/m³.

Po temeljitem mešanju s pomočjo električnega mešala smo vsako mešanico kondicionirali na ciljno vsebnost vode 11,5 %. Pred peletiranjem smo ponovno določili vlažnosti pripravljenih mešanic z merilnikom vlažnosti BEA-MA110-1.

2.2.2 Postopek peletiranja
2.2.2 Pelletization

Peletriranje smo izvedli na peletirnem stroju Kahl 14-175. Vse mešanice smo izdelali pod enakimi parametri peletiranja. Matrica je imela kanale premera 6 mm in dolžine 36 mm. Peletiranje smo izvedli pri ciljni temperaturi matrice 80 °C. Število vrtljajev mešalnika je bilo naravnano na nivo 3. Hitrost vrtenja podajalnega polža je bila 90 vrt/min, pritisnih valjev pa 1310 vrt/min. Izdelane pelete smo ohladili na pladnjih pri sobni temperaturi. Med peletiranjem smo merili porabo električne energije in kapaciteto peletiranja. Z vsako mešanico smo izdelali med 8 in 10 kg peletov s ciljno vsebnostjo vode pod 10 %.

2.2.3 Določanje kakovosti peletov
2.2.3 Pellet quality determination

Kakovost peletov smo določali po standardiziranih postopkih, prikazanih v preglednici 3. Podrobne postopke poteka določanja kakovosti peletov opisujejo Prislan et al. (2015).

Pri razvrščanju izdelanih peletov v kakovostne razrede smo upoštevali kriterije oziroma mejne vrednosti, ki jih predpisuje standard za razvrščanje nelesnih peletov SIST EN ISO 17225-6:2021.

2.2.4 Poraba energije pri peletiranju
2.2.4 Energy consumption for pelletization

Pri določanju potrebne energije za proizvodnjo peletov smo se omejili na ugotavljanje porabe energije med postopkom peletiranja in pa potrebno energijo za sušenje oz. pripravo vhodne surovine ustrezne vlažnosti. Energije, ki jo potrebujemo za zbiranje in transport vhodne surovine, v raziskavi nismo upoštevali.

Energijo za sušenje vhodne surovine smo izračunali po enačbi (1), kjer je w_1 začetna vsebnost vode v vhodni surovini, w_2 vsebnost vode v pripravljeni vhodni surovini po sušenju, T_1 je temperatura vhodne surovine pred sušenjem, c_p je specifična toplota vode in q_i je izparilna toplota vode. V izračunu smo uporabili vrednosti za specifično toploto c_p = 4181 J/kgK in izparilno toploto q_i = 2256,9 kJ/kg.

$$W = (w_1 - w_2)\ ((100 - T_1)\ c_p + q_i) \tag{1}$$

Za merjenje porabljene energije za peletiranje smo uporabili strojno in programsko opremo proizvajalca Cirkutor. Trifazni števec električne energije z oznako CEM C20 je bil z ethernet vmesnikom z oznako CEM M-ETH povezan z osebnim računalnikom. Porabo električne energije smo beležili v *.cvs datoteko s programskim paketom PowerStudio. Analizo in preračun porabe električne energije za peletiranje 1 kg peletov pa smo izvedli v programskem paketu Excel.

Preglednica 3. Postopki ugotavljanja lastnosti peletov.
Table 3. Methods of determining the pellets‘ properties.

Merjena lastnost	Postopek	Merilna naprava–oznaka
Vsebnost vode	SIST EN ISO 18134-2:2017	Memmert UFP 600
Vsebnost vode**	Metoda tehtanja	BEA-MA-110-1
Gostota nasutja*	SIST EN ISO 17828:2016	
Mehanska obstojnost	SIST EN ISO 17831-1:2016	BEA TUMBLER 2000 R
Vsebnost pepela	SIST EN ISO 18122:2023	Nabertherm LE 14/22 B 300
Kurilna vrednost	SIST EN ISO 18125:2017	Kalorimeter IKA C200 auto

*modificirana metoda, postopek opisujejo Gornik Bučar et al. (2021)
** nestandardiziran postopek, uporabljen za hitro določanje vlažnosti med peletiranjem

3 REZULTATI IN RAZPRAVA
3 RESULTS AND DISCUSSION
3.1 VHODNA SUROVINA IN NJENA PRIPRAVA
3.1 INPUT RAW MATERIAL AND ITS PREPARATION

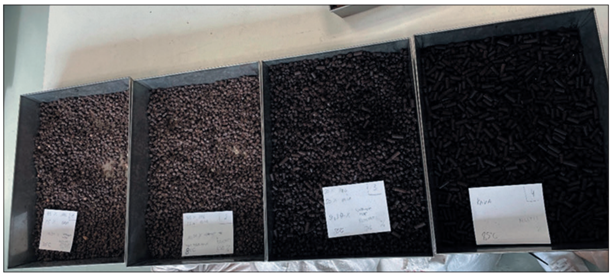
Eden od pomembnejših izzivov pri izdelavi peletov na osnovi kavnega ostanka je zagotovo njegovo zbiranje, logistika dobave in seveda sušenje. Kavni ostanek ima visoko vlažnost in vsaj v prvi fazi tudi temperaturo, kar lahko povzroča nastajanje plesni. Poleg tega kavni ostanek nastaja razpršeno, tako da je za zbiranje zadostnih količin kavnega ostanka potrebna dobra organiziranost deležnikov. Kavno usedlino, ki jo je treba čim prej osušiti, lahko sušimo na prostem (naravno sušenje), pri čemer so potrebne ustrezne površine (Anžič, 2021) ali pa tehnično v različnih sušilnih komorah. V obeh primerih je potrebno obračanje kavne preproge, da zagotovimo enakomeren potek sušenja. Po sušenju smo kavno usedlino dobro zdrobili, saj izkazuje težnjo po kepenju. Drobljenje smo izvajali ročno, s pomočjo sita z odprtinami dimenzije 3,15 mm.

Na osnovi sejalne analize smo ugotovili, da je imela žagovina 99,8 % delcev manjših od 3,15 mm (od tega je delež velikosti delcev med 1–2 mm znašal 59,9 %), medtem ko je pri kavnem ostanku 69,1 % delcev bilo v velikostnem razredu med 0,25 mm in 1,0 mm.

Pri analizi potrebne energije za sušenje vhodne surovine kavnega ostanka smo obravnavali dva vzorca dveh dobaviteljev kavnega ostanka. Povprečna vsebnost vode treh vzorcev prvega dobavitelja je bila 58,7 %, drugega pa 66,4 %. Pri pripravi mešanice z različnimi deleži kavnega ostanka za izdelavo peletov smo kavno usedlino posušili na vsebnost vode 11,5 %. Izračun potrebne energije za sušenje kavnega ostanka z enačbo (1) je za prvega dobavitelja znašal 339,8 Wh/kg za drugega pa 395,2 Wh/kg. V izračunih smo upoštevali, da je bila začetna temperatura kavnega ostanka 20 ^{o}C.

3.2 PELETIRANJE
3.2 PELLETIZATION

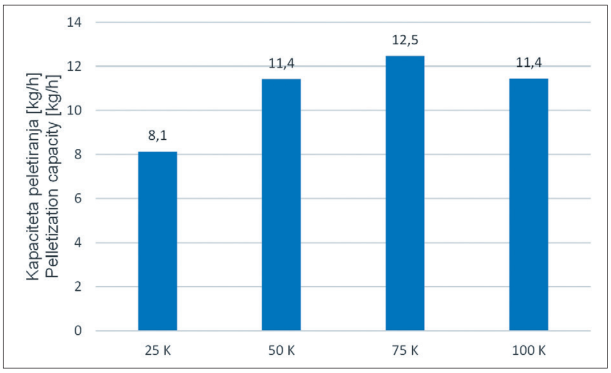
S peletiranjem ostankov kave nismo imeli nobenih izkušenj, zato smo se na podlagi dostopne literature odločili za okvirne parametre peletiranja. Atabani et al. (2023) sicer v svoji pregledni študiji podajajo celovito in podrobno analizo rabe različnih odpadnih biomaterialov in kavnega ostanka in se osredotočajo na kemijsko sestavo, vendar ne navajajo pogojev peletiranja. Podobno tudi Jeguirim et al. (2016) podrobno analizirajo termično razgradnjo peletov iz ostankov kave, vendar ne navajajo podrobno pogojev, pri katerih je potekalo peletiranje. Limousy et al. (2013) so peletirali mešanice kavnega ostanka (50 %) in žagovine bora (50 %) in izvajali peletiranje pri temperaturi 80 °C. Iz tega razloga smo izvajali peletiranje pri ciljni temperaturi 80 °C, ki pa smo jo v primeru peletiranja z večjim deležem kavnega ostanka težko vzdrževali, saj je temperatura med peletiranjem padala. Predvidevamo, da se med peletiranjem mešanic z večjim deležem kave ni generiralo zadostno trenje kavnega ostanka na matrici in stenah kanalov, kar bi pripomoglo k dvigu temperature peletiranja kavnega ostanka.



Slika 2. Peleti, izdelani z različnimi deleži kavnega ostanka in žagovine.

Figure 2. Pellets made with different proportions of spent coffee grounds and sawdust.

Kapaciteto peletiranja smo določali na osnovi mase izdelanih peletov (slika 2) in ne na osnovi mase vhodne surovine. Kapaciteta se je gibala od 8 kg/h do 12,5 kg/h (slika 3). Peleti so po peletiranju padali na sito z velikostjo odprtin 5 mm, kar pomeni, da pri izračunu kapacitete nismo upošte-



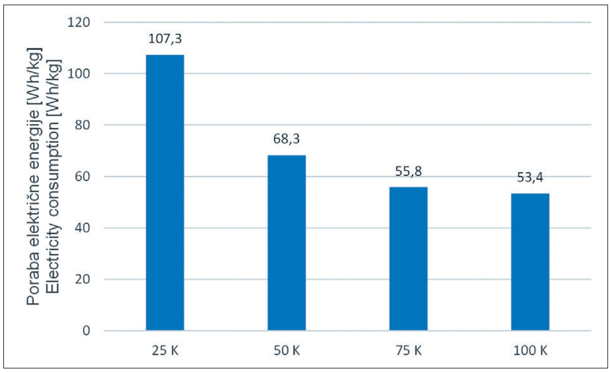
Slika 3. Kapaciteta peletiranja mešanic z različnim deležem kavnega ostanka.

Figure 3. Pelletization capacity of mixtures with different proportions of spent coffee grounds.

vali manjših delcev. To tudi pojasnjuje, zakaj je kapaciteta peletiranja 100 K (100 % kavnega ostanka) bila nižja, kljub temu, da je peletiranje potekalo popolnoma brez težav in prekinitev. Pri tem peletiranju je bil prisoten večji delež peletov, manjših od dimenzije 5 mm.

3.3 PORABA ENERGIJE ZA PELETIRANJE
3.3 ENERGY CONSUMPTION FOR PELLETIZATION

Pri peletiranju različnih mešanic z različnim deležem kavnega ostanka smo merili tudi porabo električne energije peletirnega stroja. Porabljeno električno energijo za peletiranje posamezne mešanice smo normirali na maso (kg) proizvedenih peletov. Skladno s pričakovanji se je porabljena električna energija z večanjem deleža kavnega ostanka zmanjševala od 107,3 Wh/kg za mešanico s 25 % kavnega ostanka do 53,4 Wh/kg za 100 % kavnega ostanka (slika 4).

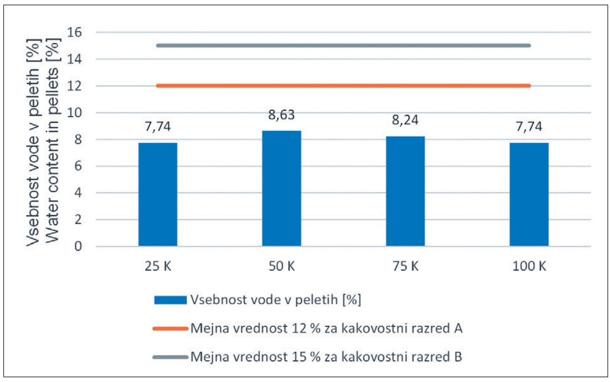


Slika 4. Poraba električne energije pri peletiranju mešanic z različnim deležem kavnega ostanka.

Figure 4. Electricity consumption during pelletization of mixtures with different proportions of spent coffee grounds.

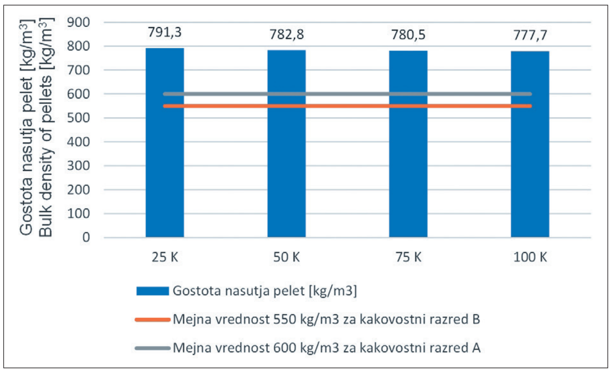
3.4 LASTNOSTI PELETOV
3.4 PROPERTIES OF PELLETS

Peletom, izdelanim iz mešanic z različnim deležem kavnega ostanka, smo izmerili lastnosti in ugotovili, da vsebnost vode (slika 5), gostota nasutja (slika 6), kurilna vrednost (slika 7) in vsebnost pepela (slika 9) izpolnjujejo zahteve za uvrstitev v najvišji kakovostni razred A po zahtevah standarda za nelesne pelete SIST EN ISO 17225-6:2021. Naraščanje deleža kavnega ostanka se odraža v naraščanju kurilne vrednosti, kar se ujema z ugotovitvami drugih avtorjev (Limousy et al., 2013; Ciesielczuk et al., 2015; Kasantiukl, 2019; Nosek et al., 2020; Woo



Slika 5. Vsebnost vode peletov, izdelanih iz mešanic z različnim deležem kavnega ostanka in mejne vrednosti za nelesne pelete.

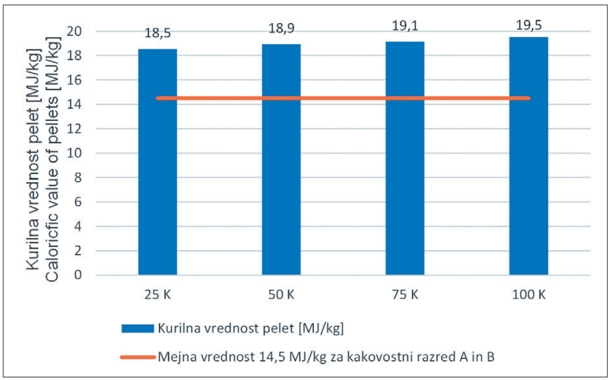
Figure 5. Water content of pellets from mixtures with different proportions of spent coffee grounds and limit values for non-wood pellets.



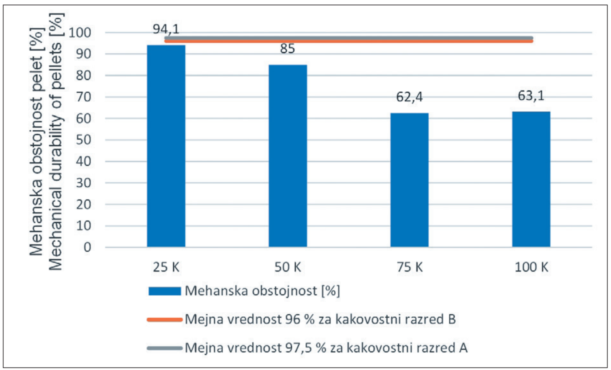
Slika 6. Gostota nasutja peletov, izdelanih iz mešanic z različnim deležem kavnega ostanka in mejne vrednosti za nelesne pelete.

Figure 6. Bulk density of pellets made from mixtures with different proportions of spent coffee grounds and limit values for non-wood pellets.

et al., 2021), in je tudi pričakovano zaradi ugodne kemijske sestave kavnega ostanka. Kritična lastnost izdelanih peletov je mehanska obstojnost (slika 8), saj peleti ne dosegajo vrednosti niti za uvrstitev v kakovostni razred B za nelesne pelete. V primeru 25 % deleža kavnega ostanka smo sicer dosegli 94,1 % mehansko obstojnost (slika 8), kar je obetajoč rezultat. Menimo, da bi z optimiranjem pogojev peletiranja te mešanice dosegli zahteve standarda za uvrstitev v najvišji kakovostni razred. S povečevanjem deleža kavne usedline v peletih se njihova mehanska obstojnost močno zmanjša. V naši raziskavi smo vse mešanice z različnim deležem kavnega ostanka peletirali z matrico, ki je imela dolžino



Slika 7. Kurilna vrednost peletov, izdelanih iz mešanic z različnim deležem kavnega ostanka in mejne vrednosti za nelesne pelete.
Figure 7. Calorific value of pellets from mixtures with different proportions of spent coffee grounds and limit values for non-wood pellets.

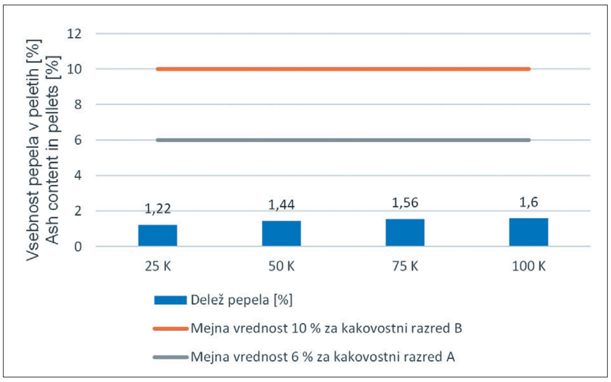


Slika 8. Mehanska obstojnost peletov, izdelanih iz mešanic z različnim deležem kavnega ostanka in mejne vrednosti za nelesne pelete.
Figure 8. Mechanical durability of pellets from mixtures with different proportions of spent coffee grounds and limit values for non-wood pellets.

kanalov 38 mm. Predvidevamo, da bi se mehansko obstojnost peletov, izdelanih iz kavnega ostanka, dalo povečati, če bi povečali dolžino kompresijskega kanala v matrici.

S povečevanjem deleža kavnega ostanka v mešanici za izdelavo peletov se povečuje tudi vsebnost pepela v izdelanih peletih (slika 9). Vendar je tudi pri peletih, izdelanih samo iz kavnega ostanka, vsebnost pepela veliko manjša od 6 %, kar je mejna vrednost za A kakovostni razred za nelesne pelete.

V raziskavi smo želeli ugotoviti možnost uporabe kavnega ostanka, ki se neizkoriščen odlaga v okolje, za proizvodnjo peletov. Že iz literaturnih po-



Slika 9. Vsebnost pepela v peletih, izdelanih iz mešanic z različnim deležem kavnega ostanka in mejne vrednosti za nelesne pelete.
Figure 9. Ash content in pellets from mixtures with different proportions of spent coffee grounds and limit values for non-wood pellets.

datkov smo pričakovali, da imajo peleti z večanjem deleža kave višjo kurilno vrednost, hkrati pa tudi večji delež pepela in slabšo mehansko odpornost, kar so potrdili tudi naši rezultati. Peleti, izdelani iz 100 % kavnega ostanka, imajo nizko mehansko obstojnost. Uporaba peletov, izdelanih iz 100 % kavnega ostanka, je manj priporočljiva, saj pride pri zgorevanju peletov iz čistega kavnega ostanka do padca temperature zgorevanja v kotlu, kar pripisujejo deležu finih delcev, ki »zadušijo« plamen. To vodi do nepopolnega izgorevanja, zaradi česar se poveča delež emisij ogljikovega monoksida, kot tudi delež emisij dušikovih oksidov (Atabani et al., 2023). Podobne ugotovitve navajajo tudi drugi (Limousy et al., 2013, Nosek et al., 2020), saj ugotavljajo, da se pri kurjenju peletov iz čistega kavnega ostanka zmanjša učinkovitost kotla in poveča delež finih delcev v dimnih plinih.

4 ZAKLJUČKI
4 CONCLUSIONS

Za zagotavljanje zelene energije in v skrbi za okolje je potrebno vključevanje različnih virov biomase kot tudi njenih ostankov in odpadkov. Lesna biomasa je zagotovo eden od najpomembnejših virov trdih biogoriv, vendar se lahko le-ta uporablja tudi v drugih rabah, ki omogočajo večjo krožnost, kaskadno rabo in doseganje višje dodane vrednosti. Kljub temu so ostanki iz žagarske industrije najpomembnejši vir vhodne surovine za izdelavo peletov, ki so standardizirano trdo biokurivo, katerega proizvodnja in raba konstantno narašča.

V raziskavi smo želeli proučiti, ali so kavni ostanki primerni za izdelavo peletov oz. ali s kavnimi ostanki lahko nadomestimo del lesne biomase v peletih. Peletiranje smo izvedli na laboratorijski peletirni napravi in izdelali pelete s 25 %, 50 %, 75 % in 100 % volumskim deležem kavnega ostanka. Izdelanim peletom smo po standardnih postopkih določili vsebnost vode, gostoto nasutja, delež pepela, kurilno vrednost in mehansko obstojnost in pri tem upoštevali zahteve standarda za nelesne pelete SIST EN ISO 17225-6:2021. Izdelani peleti, ki imajo visoko kurilno vrednost in nizko vsebnost vode, ne dosegajo kakovostnih zahtev standarda samo v primeru mehanske obstojnosti in sicer ne glede na količino kavnega ostanka.

Meritve so pokazale, da se največ energije pri peletiranju porabi za sušenje vhodne surovine. V primeru peletiranja mešanic kavnega ostanka in žagovine je smiselno sušenje kavnega ostanka optimizirati, saj je vsebnost vode v kavnem ostanku večja kot pa v svežem lesu in tako predstavlja tudi večji strošek.

Rezultati raziskave kažejo, da je kavni ostanek lahko primeren dodatek oz. substitut žagovini za izdelavo peletov, vendar je treba prilagoditi pogoje peletiranja, zelo zahtevna pa je logistika dobave kavnega ostanka in tudi njegovo sušenje.

5 POVZETEK

5 SUMMARY

Increasing energy consumption, stringent requirements to ensure the reliability of energy supply and concern for the environment in the broadest sense require the integration of a wide variety of energy sources. From the point of view of environmental protection, sustainability, the circular economy and economic efficiency, it is necessary to activate the use of a variety of bio-waste materials that remain as residual or waste materials during processing or use, and can largely replace the use of wood biomass for energy. This would also pursue the goals of the IEA (IEA, 2021) or Net Zero scenario. One such biowaste material is spent coffee grounds, which offer the potential for the production of pellets due to their availability and diverse chemical composition. In recent years, wood pellets have become a very important form of solid biofuel, intended both for individual use to generate thermal energy and for industrial use to generate heat and electricity. The use and therefore also the production of pellets is constantly increasing and has risen 2.6-fold worldwide in the last ten years. Wood pellets are currently mainly produced from sawmill residues, but most of these residues can be used more efficiently in new innovative products with great substitution potential, according to the principle of the circular economy.

The study investigated whether spent coffee grounds can be used for the production of pellets, whereby spent coffee grounds can replace part of the wood biomass (sawdust). Pelleting was carried out on a laboratory pelleting press and pellets were made using a mixture of 25% (25 K), 50% (50 K), 75% (75 K) and 100% (100 K) of spent coffee grounds with spruce sawdust. Spent coffee grounds received from a restaurant were first dried to prevent the occurrence of mold. Pelletization was carried out on a Kahl flat press at a target temperature of 80 °C, while the power consumption was monitored (Figure 4). After cooling and conditioning, we determined the water content (Figure 5), bulk density (Figure 6), calorific value (Figure 7), mechanical durability (Figure 8) and ash content (Figure 9) of the pellets and compared them with the requirements of the EN ISO 17225-6:2021 standard.

The results show that the pellets only fail to meet the requirements of the mentioned standard in the case of mechanical durability. We can conclude that spent coffee grounds have the potential to partially replace sawdust in the production of pellets (at a proportion of 50% or less), but it is necessary to adjust the pelleting conditions. It should be noted that the organization of the collection, delivery logistics and drying of spent coffee grounds is very demanding and yet crucial for the successful activation of spent coffee grounds for pellet production.

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EFFECTS OF APPLYING WAX ON THE COLOUR, GLOSSINESS, AND WHITENESS INDEX VALUES OF AMERICAN BLACK CHERRY *(Prunus serotina)* WOOD

VPLIV NANOSA VOSKA NA BARVO, SIJAJ IN INDEKS BELINE LESA AMERIŠKE ČREMSE *(Prunus serotina)*

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Abstract / Izvleček

Abstract: In this study, the effects of applying wax on the colour, glossiness, and whiteness index (*WI**) values of American black cherry (*Prunus serotina* Ehrh.) wood were investigated. Wax was applied to wooden material surfaces using a brush in one, two, and three layers. Tests were then conducted on surfaces with and without wax. The results were statistically significant according to the multivariate variance analysis. It was determined that the application of wax led to a decrease in *L**, *h*°, and *WI** values on the wooden material surfaces (parallel and perpendicular to the fibres), while the *a**, *b**, and *C** parameters increased. In measurements parallel and perpendicular to the fibres, increases were observed in gloss values for two- and three-layer wax applications at 60° and 85°. The Δ*L** values were negative when wax was applied in one, two, and three layers, whereas the Δ*a**, Δ*b**, and Δ*C** values were positive. The Δ*E** values were determined as 8.41 for one layer of wax, 11.29 for two layers, and 11.59 for three layers. Given the similarity between the Δ*E** values of two and three layers of wax, it can be inferred that a third layer may not be necessary.

Keywords: American black cherry = *Prunus serotina*, wood, surface treatment, wax, colour, Glossiness, whiteness index

Izvleček: Proučevali smo vpliv nanosa voska na barvo, sijaj in indeks beline (*WI**) lesa ameriške čremse (*Prunus serotina* Ehrh.). Vosek je bil nanesen na površine lesa s čopičem v enem, dveh in treh slojih. Teste smo opravili na premazanih in nepremazanih površinah. Analiza variance je pokazala statistično značilne razlike v rezultatih. Medtem ko smo po nanosu voska opazili zmanjšanje vrednosti *L**, *h*° in *WI** v smereh vzporedno in pravokotno na vlakna, smo ugotovili, da so parametri *a**, *b** in *C** po nanosu narasli. Pri merjenju sijaja pri 60 in 85 stopinjah smo pri vzorcih z dvema in tremi plastmi voska opazili povečanje vrednosti pri merjenju vzporedno in pravokotno glede na smer lesnih vlaken. Vrednosti *ΔL** so bile negativne za voskane sisteme, nanesene v 1, 2 in 3 slojih, medtem ko so bile vrednosti *Δa**, *Δb** in *ΔC** pozitivne. Vrednost *ΔE** je po 1-slojnem voskanju znašala 8,41, pri 2-slojnem 11,29 in pri 3-slojnem 11,59. Glede na to, da so bile vrednosti *ΔE** po 2 in 3 nanosih voska podobne, lahko sklepamo, da 3. nanos voska ni potreben.

Ključne besede: ameriška čremsa = *Prunus serotina*, les, površinska obdelava, vosek, barva, sijaj, indeks beline

1 INTRODUCTION
1 UVOD

Waxes are esters resulting from the combination of long-chain carboxylic acids and alcohols. Apart from organic waxes like beeswax or carnauba wax, there are also naturally occurring fossil waxes sourced from petroleum or lignite. Additionally, synthetic variations such as hydrocarbon or amide waxes are available. These can undergo modifications through oxidation or other chemical processes (Illmann et al., 1983; Scholz et al., 2010).

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Waxes are commonly utilized within hot melt formulations to diminish surface tension and decrease melt viscosity. Certain wax varieties, such as microcrystalline waxes, bolster the hot melt by forming crystallites that withstand deformation under load. These are incorporated into formulations requiring relatively high yield strength, acting as additives to enhance overall performance (Pizzi & Kumar, 2019).

In recent times, growing attention to environmental protection has driven advances in the wax formulations used for protecting wood. These waxes boast low pollutant content and are sourced from renewable materials. As a result, they have gained widespread use as additives in wood preservation and waterproofing (Evans et al., 2005; Schultz et al., 2007; Niu & Song, 2021).

The literature reports the application of wax-based chemicals on various wood species, along with tests conducted on factors such as colour and glossiness (Peker et al., 2024a; b; c; Kaplan et al., 2024; Liu et al., 2022; Akçay, 2020; Çamlıbel & Ayata, 2024a; b; c). However, it has been observed that to date the application of wax on American black cherry wood has not been reported in the literature.

American black cherry (*Prunus serotina* Ehrh.) is one of the most important timbers in the furniture and interior design sectors worldwide, thanks to its appealing reddish-brown heartwood hue and delicate texture (Schardt, 2004). Historical accounts suggest that black cherry was brought from North America, where it is native, to South America and Europe by colonists during the 17th century. It gained commercial significance in Ecuador and was noted as an invasive species in numerous European countries (Starfinger et al., 2003; Popenoe & Pachano, 1922). Since the late 19th century, it has served as an auxiliary tree in forestry, primarily in Germany but also in the Netherlands (Eijsackers & Oldenkamp, 1976), Belgium (Van den Meersschaut & Lust, 1997; Godefroid et al., 2005) and Slovenia (Pintar et al., 2020).

Black cherry thrives across Eastern North America, adapting well to a diverse range of soils, especially in regions with cool and humid summers. While it commonly grows near sea level in Canada, it also thrives at elevations of 1520 meters or higher in the Appalachian Mountains (Hough, 1965).

The fruit of black cherry is a vital food source for numerous non-migratory birds, squirrels, deer, turkeys, mice, moles, and various other wildlife species. However, the leaves, branches, and bark of cherry trees contain cyanogenic glycoside, primarily in the form of prunasin, which releases cyanide when damaged (Horsley, 1981). Pets or livestock consuming wilted leaves may thus suffer illness or death due to cyanide poisoning (Kingsbury, 1964).

Black cherry seeds need a ripening period to facilitate germination (Grisez, 1974). Typically, this ripening process occurs on the forest floor during the winter months in natural settings. The typical trend is for seeds from a one-year crop to germinate in the subsequent three or more years (Marquis, 1975; Wendel, 1972). Late spring frosts have the potential to harm blossoms before they fully open, and occasionally frosts can cause a significant number of newly emerged fruits to fall from the stems before ripening (Hough, 1965).

Black cherry tree flowers are white, solitary, and arranged in umbel-like clusters. They are perfect flowers, pollinated by insects (Grisez, 1974). Various bee species, including honeybees, as well as several species of flies and a flower beetle, are known to visit the flowers for pollen and nectar (Forbes, 1973). The wood from this tree species is prized for its durability and excellent workability, making it highly sought after for furniture and cabinet production (Kitzmiller, 1968).

In this particular cherry wood (*Prunus serotina* Ehrh.), the ethanol-toluene-water solubility is determined as 3.10%, ethanol-toluene solubility as 2.02%, and ethanol-water solubility as 4.79% (Nzokou & Kamdem, 2005).

This study investigates the effects of applying wax in different numbers of layers on the colour, gloss, and whiteness index (*WI**) values of American black cherry (*Prunus serotina* Ehrh.) wood.

2 MATERIALS AND METHODS
2 MATERIAL IN METODE
2.1 WOOD MATERIAL
2.1 LES

American black cherry (*Prunus serotina* Ehrh.) wood was cut into samples with the dimensions of 100 mm x 100 mm x 15 mm. The samples were prepared following the TS ISO 13061-1 (2021) standard. For each group, five samples were prepared. The samples were created from specimens that were knot-free, crack-free, and without fungal decay.

2.2 WAX
2.2 VOSEK

A mixture of natural and synthetic waxes was used in this study. The properties of this wax were as follows: appearance: paste; colour: neutral; odour: characteristic; solubility in water: dispersible but not soluble; dry residue: 30%; pH value: 7.6. However, the producer of the mixture did not reveal the exact chemical composition of the waxes as this is considered a commercial secret.

2.3 APPLICATION OF WAX TO WOOD MATERIAL SURFACES
2.3 NANOS VOSKA NA POVRŠINO LESA

Initially, all samples were sanded with 120, 150, and 180 grit sandpapers. Subsequently, the surfaces of the samples were cleaned of dust using a compressor. The wax mixture consisting of natural and synthetic waxes was applied to wooden material surfaces in one, two and three layers with the help of a brush.

2.4 DETERMINATION OF GLOSSINESS PROPERTIES
2.4 DOLOČITEV SIJAJA

Glossiness assessments were performed at 20°, 60°, and 85° angles, both perpendicular and parallel to the fibres, employing an ETB-0833 model gloss meter device in accordance with the ISO 2813 (1994) standard.

2.5 DETERMINATION OF COLOUR PROPERTIES
2.5 DOLOČITEV BARVE

The samples' colour alteration was assessed utilizing a CS-10 (CHN Spec, China) apparatus, adhering to the ASTM D 2244-3 (2007) standard and employing the CIELAB colour model. The evaluations were conducted utilizing a CIE 10° standard observer and CIE D65 light source within an 8/d illuminating environment (8°/diffused illumination). Δ*E** colour difference visual assessment comparison criteria (DIN 5033, 1979) are provided in Table 1.

Table 1. Comparison criteria for evaluating Δ*E** values (DIN 5033, 1979).
Preglednica 1. Primerjalna merila za ocenjevanje vrednosti Δ*E** (DIN 5033, 1979).

Δ*E** values	Visual colour score difference
<0.20	Imperceptible
0.20 - 0.50	Very weak
0.50 - 1.50	Weak
1.50 - 3.00	Noticeable
3.00 - 6.00	Very noticeable
6.00 - 12.00	Strong
> 12.00	Very strong

The following formulas were used to determine the results of total colour differences.

$$C^* = \left[(a^*)^2 + (b^*)^2 \right]^{0.5} \quad (1)$$

$$h^o = arctan\ (b^*/a^*) \quad (2)$$

$$\Delta C^* = \left(C^*_{treated\ experimental\ sample} - C^*_{untreated\ experimental\ sample} \right) \quad (3)$$

$$\Delta a^* = \left(a^*_{treated\ experimental\ sample} - a^*_{untreated\ experimental\ sample} \right) \quad (4)$$

$$\Delta L^* = \left(L^*_{treated\ experimental\ sample} - L^*_{untreated\ experimental\ sample} \right) \quad (5)$$

$$\Delta b^* = \left(b^*_{treated\ experimental\ sample} - b^*_{untreated\ experimental\ sample} \right) \quad (6)$$

$$\Delta H^* = \left[(\Delta E^*)^2 - (\Delta L^*)^2 - (\Delta C^*)^2 \right]^{0.5} \quad (7)$$

$$\Delta E^* = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2 \right]^{0.5} \quad (8)$$

Table 2. Results of Analysis of Variance.
Preglednica 2. Rezultati analize variance.

Dependent Variable	Sum of Squares	df	Mean Square	F	Sig.
Lightness (*L**)	668.258	3	222.753	2041.807	0.000*
Red (*a**) colour tone	203.047	3	67.682	1086.805	0.000*
Yellow (*b**) colour tone	8.533	3	2.844	15.691	0.000*
Chroma (*C**) value	90.189	3	30.063	195.355	0.000*
Hue (*h*°) angle	618.653	3	206.218	502.806	0.000*
Glossiness at ⊥20°	1.157	3	0.386	187.622	0.000*
Glossiness at ⊥60°	110.339	3	36.780	356.699	0.000*
Glossiness at ⊥85°	562.116	3	187.372	3967.878	0.000*
Glossiness at ‖20°	1.713	3	0.571	63.240	0.000*
Glossiness at ‖60°	172.093	3	57.364	1013.801	0.000*
Glossiness at ‖85°	1320.987	3	440.329	6940.387	0.000*
*WI** perpendicular to fibres	401.211	3	133.737	3933.441	0.000*
*WI** parallel to fibres	143.779	3	47.926	3877.180	0.000*
*: Significant					

The definitions of Δ*C**, Δ*a**, Δ*H**, Δ*b**, and Δ*L** are provided below (Lange, 1999):

Δ*a**: Positive indicates the sample is redder than the reference, and negative indicates the sample is greener than the reference.

Δ*L**: Positive indicates the sample is lighter than the reference, and negative indicates the sample is darker than the reference.

Δ*b**: Positive indicates the sample is more yellow than the reference, and negative indicates the sample is bluer than the reference.

Δ*H**: Represents the hue or shade difference.

Δ*C**: Represents the chroma or saturation difference. Positive indicates the sample is clearer and brighter than the reference, while negative indicates the sample is duller and hazier than the reference.

2.6 DETERMINATION OF WHITENESS INDEX (*WI**) CHARACTERISTICS
2.6 DOLOČITEV BELINE

In this study, measurements of whiteness index (*WI**) values were determined using the Whiteness Meter BDY-1 device and ASTM E313-15e1 standard, conducted in both parallel and perpendicular directions to the fibres.

2.7 CALCULATION OF TEST DATA
2.7 OBDELAVA PODATKOV

Standard deviations, maximum and minimum mean values, measurement values corresponding to the mean, homogeneity groups, multivariate analysis of variance, and percentage (%) change rates were calculated using a statistical programme and measurement values from the study.

3 RESULTS AND DISCUSSION
3 REZULTATI IN DISKUSIJA

The results of the analysis of variance are provided in Table 2. It is observed that the wax layer application factor was significant for all tests (Table 2).

The measurement results for the colour parameters are presented in Table 3. Upon examination of these results, it is observed that the highest *L** value (54.62) is found in the samples of the control experimental group, while the lowest result (44.49) is obtained in the group treated with three layers of wax. The highest decrease rate for the *L** value, at 18.55%, is observed in the samples treated with three layers of wax, while the lowest decrease rate, at 13.38%, is found in the samples treated with one layer of wax (Table 3).

Table 3. Measurement results for colour parameters.
Preglednica 3. Rezultati meritev barvnih parametrov.

Test	Wax Application	Number of Measurements	Mean	Change (%)	Homogeneity Group	Standard Deviation	Mini-mum	Maxi-mum	Coefficient of Variation
*L**	Control	10	54.62	-	A*	0.33	54.14	55.06	0.61
	1 layer	10	47.31	↓13.38	B	0.17	47.02	47.66	0.37
	2 layers	10	44.77	↓18.03	C	0.19	44.49	45.05	0.43
	3 layers	10	44.49	↓18.55	C**	0.51	43.78	45.09	1.14
*a**	Control	10	10.48	-	D**	0.18	10.23	10.72	1.72
	1 layer	10	14.55	↑38.84	C	0.14	14.34	14.77	0.95
	2 layers	10	15.86	↑51.34	B	0.17	15.57	16.07	1.08
	3 layers	10	16.10	↑53.63	A*	0.41	15.51	16.70	2.55
*b**	Control	10	21.20	-	C**	0.36	20.49	21.82	1.71
	1 layer	10	22.09	↑4.20	AB	0.30	21.65	22.58	1.34
	2 layers	10	22.46	↑5.94	A*	0.27	21.96	23.00	1.20
	3 layers	10	21.79	↑2.78	B	0.66	21.12	23.05	3.03
*C**	Control	10	23.65	-	D**	0.39	22.90	24.32	1.64
	1 layer	10	26.46	↑11.88	C	0.22	26.08	26.86	0.85
	2 layers	10	27.50	↑16.28	A*	0.26	27.01	27.93	0.93
	3 layers	10	27.09	↑14.55	B	0.59	26.55	28.35	2.18
h°	Control	10	63.70	-	A*	0.29	63.29	64.26	0.45
	1 layer	10	56.63	↓11.10	B	0.52	55.98	57.27	0.92
	2 layers	10	54.77	↓14.02	C	0.40	54.40	55.45	0.72
	3 layers	10	53.54	↓15.95	D**	1.06	51.66	54.78	1.99

*: Indicates the highest value and **: Indicates the lowest value

In the control experimental group, the lowest *a** value recorded was 10.48, while the group treated with three layers of wax showed the highest value at 16.10. Among the different wax application groups, the samples treated with three layers exhibited the highest increase rate for the *a** value, reaching 53.63%. Conversely, the samples treated with only one layer of wax demonstrated the lowest increase rate, standing at 38.84% (refer to Table 3).

The *b** value was at its lowest in the samples from the control experimental group, measuring 21.20, while the group treated with two layers of wax showed the highest value at 22.46. Among the various wax application groups, those treated with two layers experienced the most significant increase in the *b** value, reaching 5.94%. Conversely, the samples treated with three layers of wax exhibited the smallest increase rate, standing at 2.78%. The samples from the control experimental group yielded the lowest *C** value at 23.65, while the group treated with two layers of wax showed the least value at 27.51. Among the varied wax application groups, those treated with two layers exhibited the most substantial increase rate for the *C** value, reaching 16.28%. In contrast, the samples treated with only one layer of wax had the lowest increase rate, standing at 11.88%. The *h°* value peaked in the samples from the control experimental group, reaching 63.70, while it hit its lowest point in the group treated with three layers of wax, measuring 53.54. Among the wax application groups, the samples treated with three layers experienced the most significant decrease in the *h°* value, with a decrease rate of 15.95%. Conversely, the samples

Table 4. Results for Total Colour Differences.
Preglednica 4. Rezultati za skupne barvne razlike.

Wax Application	Δ*L**	Δ*a**	Δ*b**	Δ*C**	Δ*H**	Δ*E**	Colour Criterion (DIN 5033, 1979)
1 layer	-7.30	4.07	0.89	2.80	3.08	8.41	Strong (6.00 to 12.00)
2 layers	-9.85	5.38	1.26	3.84	3.97	11.29	
3 layers	-10.12	5.62	0.59	3.43	4.48	11.59	

treated with one layer of wax showed the smallest decrease rate, at 11.10% (see Table 3 for details).

The findings in the literature suggest that the application of wax on various types of wood, including olive, ebony Macassar, plum, and balau red, led to alterations in colour parameters, glossiness values, and whiteness index values (Peker et al., 2024 a; b; c; Kaplan et al., 2024). Moreover, investigations into European walnut, European maple, as well as beech, lime, poplar, and pine woods, have documented a reduction in the *L** value alongside an increase in the *a** and *b** values post-wax application (Liu et al., 2022; Akçay, 2020).

The results for total colour differences are provided in Table 4. One, two and three layers of wax resulted in negative Δ*L** values (darker than the reference), while the Δ*a** (redder than the reference), Δ*b** (yellower than the reference), and Δ*C** (clearer, brighter than the reference) values were positive. The Δ*E** values were determined as 8.41 for one layer of wax, 11.29 for two layers, and 11.59 for three layers, with the Δ*E** values for two and three layers of wax being very close to each other. The Δ*H** values were obtained as 3.08, 3.97, and 4.48 as the number of wax layers increased from one to three, respectively. Comparing the Δ*E** values obtained using the colour change criteria (DIN 5033, 1979), all three wax treatments fell under the "strong (6.0 to 12.0)" category (Table 4).

The measurement results for the whiteness index (*WI**) values are presented in Table 5. As the number of layers increased, the *WI** values decreased in both parallel and perpendicular directions to the fibres. The highest results for *WI** values in both parallel and perpendicular directions to the fibres were observed in the samples from the control experimental group (13.52 and 7.58, respectively), while the lowest results were found in the group treated with 3 layers of wax (5.48 and 2.94, respectively). The highest decrease rates for *WI** values in both directions were 59.47% and 61.21%, respectively, observed in the samples treated with 3 layers of wax, while the lowest decrease rates were 37.72% and 54.22%, respectively,

Table 5. Measurement results for whiteness index (*WI**) values.
Preglednica 5. Rezultati meritev vrednosti indeksa beline (WI*).

Test	Wax Application	Number of Measurements	Mean	Change (%)	Homogeneity Group	Standard Deviation	Minimum	Maximum	Coefficient of Variation
*WI** ⊥	Control	10	13.52	-	A*	0.32	13.00	13.90	2.39
	1 layer	10	8.42	↓37.72	B	0.08	8.30	8.50	0.94
	2 layers	10	6.08	↓55.03	C	0.12	5.90	6.20	2.02
	3 layers	10	5.48	↓59.47	D**	0.10	5.40	5.60	1.88
*WI** ‖	Control	10	7.58	-	A*	0.12	7.40	7.70	1.62
	1 layer	10	3.47	↓54.22	B	0.05	3.40	3.50	1.39
	2 layers	10	3.26	↓56.99	C	0.17	3.10	3.50	5.25
	3 layers	10	2.94	↓61.21	D**	0.05	2.90	3.00	1.76

*: Indicates the highest value and **: Indicates the lowest value

Table 6. Measurement results for glossiness values.
Preglednica 6. Rezultati meritev za vrednosti sijaja.

Test	Wax Application	Number of Measurements	Mean	Change (%)	Homogeneity Group	Standard Deviation	Mini-mum	Maxi-mum	Coefficient of Variation
⊥20°	Control	10	0.20	-	C	0.00	0.20	0.20	0.00
	1 layer	10	0.10	↓50.00	D**	0.00	0.10	0.10	0.00
	2 layers	10	0.45	↑125.00	B	0.05	0.40	0.50	11.71
	3 layers	10	0.51	↑155.00	A*	0.07	0.40	0.60	14.47
⊥60°	Control	10	1.51	-	C**	0.09	1.40	1.60	5.80
	1 layer	10	1.71	↑13.25	C	0.09	1.60	1.80	5.12
	2 layers	10	4.75	↑214.57	B	0.14	4.60	4.90	2.85
	3 layers	10	5.09	↑237.09	A*	0.62	4.30	5.90	12.09
⊥85°	Control	10	0.25	-	C**	0.14	0.10	0.40	54.16
	1 layer	10	0.95	↑280.00	B	0.14	0.80	1.10	14.25
	2 layers	10	8.17	↑3168.00	A*	0.20	7.90	8.40	2.45
	3 layers	10	7.99	↑3096.00	A	0.33	7.40	8.30	4.19
|| 20°	Control	10	0.30	-	B	0.00	0.30	0.30	0.00
	1 layer	10	0.14	↓53.33	C**	0.05	0.10	0.20	36.89
	2 layers	10	0.65	↑116.67	A*	0.14	0.50	0.80	20.83
	3 layers	10	0.58	↑93.33	A	0.12	0.40	0.70	21.19
|| 60°	Control	10	1.96	-	C	0.27	1.60	2.30	13.86
	1 layer	10	1.75	↓10.71	C**	0.14	1.60	1.90	7.74
	2 layers	10	5.44	↑177.55	B	0.25	5.00	5.60	4.52
	3 layers	10	6.44	↑228.57	A*	0.27	6.00	6.80	4.22
|| 85°	Control	10	2.20	-	C	0.23	1.90	2.50	10.50
	1 layer	10	1.50	↓31.82	D**	0.08	1.40	1.60	5.44
	2 layers	10	11.86	↑439.09	B	0.13	11.80	12.10	1.07
	3 layers	10	14.50	↑559.09	A*	0.42	13.80	15.00	2.91

*: Indicates the highest value and **: Indicates the lowest value

found in the samples treated with 1 layer of wax (Table 5).

The measurement results for glossiness values are provided in Table 6, and it can be seen that decreases in these were observed for samples with one layer of wax at 20°, both parallel and perpendicular to the fibres (reductions of 53.33% and 50.00%, respectively). Additionally, increases in glossiness values were observed for samples with two and three layers of wax at 60° and 85°, both parallel and perpendicular to the fibres (Table 6).

It was determined that the glossiness values changed compared to the control samples with application of wax. While a decrease was observed in glossiness values for samples with a single layer of wax compared to control samples at 60° and 85° parallel to the fibres (10.71% and 31.82%, respectively), a contrasting situation was observed for the same angular directions in samples with one layer of wax perpendicular to the fibres (13.25% and 280.00%, respectively). Additionally, glossiness values for all degrees parallel to the fibres were higher than those perpendicular to the fibres (Table 6).

4 CONCLUSION
4 ZAKLJUČKI

This study is important because it shows whether there is any negative interaction between the wood of a particular tree species and the wax coating used.

Furthermore, the following conclusions were derived from the results:

- Δ*L** values were negative for the samples with wax applied in one, two and three layers, while Δ*a**, Δ*b**, and Δ*C** values were positive. Δ*E** values were determined as 8.41 for one layer of wax, 11.29 for two layers, and 11.59 for three.
- It was found that the application of wax on wooden surfaces led to a decrease in *L**, *h*°, and WI* values (for both parallel and perpendicular directions), while the *a**, *b**, and *C** parameters increased.
- Multivariate analysis of variance results were significant for all tests.
- Increases in glossiness values were observed for both parallel and perpendicular directions to the fibres at 60° and 85° angles for surfaces treated with two and three layers of wax.
- The Δ*E** values for two and three layers of wax were very close to each other, suggesting that the application of a third layer may not be necessary.

5 SUMMARY
5 POVZETEK

Preučili smo učinke različnih nanosov voska na barvo, sijaj in vrednost indeksa beline (WI*) lesa ameriške vrste *Prunus serotina* Ehrh., s slovenskimi imeni ameriška čremsa (Pintar et al., 2020) in tudi pozna čremsa ali ameriška črna češnja (Brus, osebna komunikacija). Zaradi privlačnega rdečkasto-rjavega odtenka jedrovine in nežne teksture je ta vrsta lesa trenutno ena pomembnih uvoženih lesnih vrst za proizvodnjo pohištva in notranje opreme (Schardt, 2004).

Vzorce lesa ameriške čremse smo pripravili v dimenzijah 100 mm x 100 mm x 15 mm. Mešanica naravnih in sintetičnih voskov je bila s čopičem nanesena na površino lesa v 1, 2 in 3 slojih, kontrolni vzorci pa so bili brez površinske obdelave.

Na voskanih in nevoskanih površinah so bili opravljeni preskusi sijaja (ISO 2813, 1994), spremembe barve (ASTM D 2244-3, 2007) in indeksa beline (*WI**) v vzporedni in pravokotni smeri na vlakna (ASTM E313-15e1, 2015). Rezultate smo medsebojno primerjali.

Glede na rezultate analize variance je bilo ugotovljeno, da je bilo število nanesenih plasti voska pomembno za vse preskuse.

Pri pregledu rezultatov je bilo ugotovljeno, da je bila najvišja vrednost svetlosti barve (*L**) ugotovljena pri vzorcih kontrolne skupine, najnižja pa pri skupini, obdelani s tremi plastmi voska.

Največje zmanjšanje vrednosti *L**, 18,55 %, je bilo ugotovljeno pri vzorcih s tremi plastmi voska, najmanjše zmanjšanje, 13,38 %, pa pri vzorcih z eno plastjo voska.

V kontrolni skupini je bila najnižja zabeležena barvna vrednost, ki predstavlja rdeče-zeleno os v sistemu *a** 10,48, medtem ko je bila v skupini, obdelani s tremi plastmi voska, najvišja vrednost 16,10. Med skupinami z nanosom voska se je vrednost *a** najbolj povečala pri vzorcih s tremi plastmi, in sicer za 53,63 %, medtem ko se je pri vzorcih z eno plastjo povečala najmanj, in sicer za 38,84 %.

Barvna vrednost *b**, ki predstavlja rumeno-modro os v sistemu, je bila najnižja pri vzorcih kontrolne skupine in je znašala 21,20, najvišja pa pri skupini, obdelani z dvema plastema voska, in sicer 22,46. Vrednost *b** se je najbolj povečala pri vzorcih z dvema plastema voska, in sicer za 5,94 %, najmanj, za 2,78 %, pa pri vzorcih s tremi plastmi.

Kontrolna skupina je imela najnižjo vrednost kromatičnosti *C**, 23,65, skupina z dvema plastema voska pa najvišjo, 27,51. Med skupinami z nanosom voska se je vrednost *C** najbolj povečala pri vzorcih z dvema plastema, in sicer za 16,28 %, pri vzorcih z eno plastjo pa je bilo povečanje najmanjše, in sicer za 11,88 %.

Vrednost *h*° je bila najvišja pri 63,70 v kontrolni skupini, najnižja pa pri 53,54 v skupini, obdelani s tremi plastmi voska. Pri vzorcih s tremi plastmi se je vrednost *h*° najbolj zmanjšala, in sicer za 15,95 %, medtem ko se je pri vzorcih z eno plastjo zmanjšala najmanj, in sicer za 11,10 %.

Kar zadeva sijaj, je bilo pri vzorcih z enim slojem voska opaženo zmanjšanje pri 20 stopinjah, tako vzporedno kot pravokotno na vlakna. Nasprotno se je sijaj povečal pri vzorcih z dvema in tremi plastmi voska pri 60 in 85 stopinjah v obe smeri.

Uporaba voska je spremenila vrednosti sijaja v primerjavi s kontrolnimi vzorci. Pri vzorcih z enim slojem voska pri 60 in 85 stopinjah vzporedno z vlakni se je sijaj zmanjšal, pri istih vzorcih pravokotno na vlakna pa se je povečal. Vrednosti sijaja vzporedno z vlakni so bile višje kot pravokotno na vlakna.

Z večanjem števila plasti voska so se vrednosti beline *WI** v obeh smereh glede na vlakna zmanjševale. Vzorci kontrolne skupine so imeli najvišje vrednosti *WI** v obeh smereh, najnižje vrednosti pa so bile v skupini s tremi plastmi voska.

Najvišja stopnja zmanjšanja vrednosti *WI** je bila 59,47 % oziroma 61,21 % pri vzorcih s tremi plastmi voska, najnižja stopnja zmanjšanja pa 37,72 % oziroma 54,22 % pri vzorcih z eno plastjo voska.

Vrednosti spremembe barve Δ*E** so bile 8,41 za eno plast, 11,29 za dve plasti in 11,59 za tri plasti voska, pri čemer so bile vrednosti za dve in tri plasti zelo podobne. Vrednosti spremembe kota barvnega tona Δ*H** so bile 3,08, 3,97 in 4,48 za eno, dve in tri plasti voska.

Glede na podobnost vrednosti Δ*E** pri dvoslojnem in troslojnem nanosu voska lahko sklepamo, da tretji nanos voska morda ni potreben.

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Razstava Čar lesa 2024

The Charm of Wood Exhibition, 2024

Jure Žigon, Luka Krže, Franc Pohleven

S slavnostno prireditvijo v Cankarjevem domu v Ljubljani smo v ponedeljek, 13. maja 2024, odprli promocijsko razstavo Čar lesa 2024, ki letos poteka že 16. leto zapored. Razstava je bila tam na ogled do 19. maja 2024.

Slavnostni govorec na odprtju razstave je bil minister za gospodarstvo, turizem in šport gospod Matjaž Han, ki je razstavo v Cankarjevem domu tudi uradno odprl. Dogodek je povezovala gospa Petra Korošec iz Javne agencije SPIRIT. Na govorniškem odru ob odprtju razstave so se zvrstili izr. prof. dr. Maks Merela, prodekan Oddelka za lesarstvo Biotehniške fakultete Univerze v Ljubljani, gospod Rok Capl, direktor Javne agencije SPIRIT Slovenija, gospod Oskar Kogoj, industrijski oblikovalec in gospa Eva Knez, državna sekretarka na Ministrstvu za kmetijstvo, gozdarstvo in prehrano. Svoje videnje o razstavi je kot idejni vodja, pobudnik in organizator dodal tudi prof. dr. Franc Pohleven, ki se je v svojem govoru najlepše zahvalil razstavljavcem, govorcem, podpornikom, organizatorjem in vsem, ki so pomagali pri realizaciji dogodka. Kot so na odprtju poudarili vsi govorci, je razstava pomembna za promocijo predelave in uporabe lesa ter lesarskih poklicev.

Na koncu je sledila še zahvala in predaja plakete dosedanjemu predsedniku Društva za zaščito lesa Slovenije gospodu Borutu Kričeju, ki mu jo je izročil novi predsednik društva dr. Jure Žigon.

Odprtje je z glasbenimi vložki dopolnil akustični duo Urban & Katarina. Povezovalka dogodka Petra Korošec je ob zaključku podala podatke o letošnji razstavi v Cankarjevem domu. Zbrane je povabila k udeležbi na dogodku »Izdelek se predstavi«, kjer razstavljavci svoje izdelke predstavljajo obiskovalcem razstave, in prisotne povabila na pogostitev in ogled čarobnih izdelkov iz lesa.

Naslednje dni smo na razstavi poleg drugih obiskovalcev gostili tudi več kot 150 učencev in učiteljev osnovnih šol, za katere smo pripravili predavanja in delavnice o lesu ter jih vodeno popeljali po razstavi.

Glavni namen razstav Čar lesa je ozaveščanje potrošnikov o trajnostnem pomenu predelave lesa in uporabe lesnih izdelkov. Društvo za zaščito lesa

Slika 1. Utrinek s slovesnega odprtja razstave Čar lesa 2024 v Cankarjevem domu v Ljubljani (Foto: Luka Krže).

Figure 1. A photograph from the opening ceremony of the Čar lesa 2024 / *Charm of Wood* 2024 exhibition in Cankarjev dom in Ljubljana (Photo: Luka Krže).

Slovenije in Svet za les s tem namenom razstavo organizirata že od leta 2009, na različnih lokacijah po Sloveniji. Vsaka razstava je unikatna, saj so nanje povabljeni tudi proizvajalci in umetniki, ki delujejo v okolici kraja razstave. Želimo si, da se na vsaki od razstav prikaže tudi lesene izdelke, značilne za okolje, kjer se razstava nahaja. Skupno vsem razstavam je, da so razstavljeni izdelki označeni s količino ogljikovega dioksida (CO_2), ki jo izdelek prispeva k znižanju CO_2 v ozračju in s tem vpliva na normalizacijo podnebja, kar je zaradi pričujočih podnebnih sprememb še kako pomembno.

Razstava Čar lesa bo v letu 2024 med navedenimi datumi obiskala še naslednje kraje po Sloveniji:

- Volčji potok, Arboretum: od 21. maja do 2. junija 2024
- Semič, Kulturni center Semič: od 4. do 26. junija 2024
- Sodražica, dvorana OŠ dr. Ivan Prijatelj Sodražica: od 28. junija do 21. julija 2024
- Murska Sobota, paviljon Expano: od 23. julija do 3. septembra 2024
- Laško, Muzej Laško: od 5. do 25. septembra 2024
- Pivka, Krpanov dom Pivka: od 27. septembra do 15. oktobra 2024
- Nova Gorica, avla Občine N. Gorica: od 17. oktobra do 12. novembra 2024
- Ljubljana, GR – Sejem Ambient od 14. do 17. novembra 2024

Vljudno vabljeni na ogled razstav!

Slika 2. Razstava Čar lesa 2024 v Cankarjevem domu (Foto: Luka Krže).
Figure 2. Čar lesa 2024 / *Charm of Wood* 2024 exhibition in Cankarjev dom in Ljubljana (Photo: Luka Krže).

Slika 3. Utrinek s predavanja za učence osnovnih šol (Foto: Davor Kržišnik).
Figure 3. A photograph of a lecture for primary school students (Photo: Davor Kržišnik).

The *Charm of Wood* 2024 promotional exhibition, now in its 16th consecutive year, opened on May 13th 2024 with a gala event in Cankarjev dom in Ljubljana. The exhibition was on display until May 19th 2024.

The main aim of the *Charm of Wood* exhibitions is to raise awareness of the sustainable importance of using wood and wood products. The Slovenian Wood Protection Association and the Wood Council have been organizing the exhibition at various locations in Slovenia since 2009, with the goal of promoting the use of wood and wood products. Each exhibition is unique, as producers and artists working in the vicinity of the respective exhibition are invited to participate with their products. Each exhibition also features wood products that are typical of the environment in which the exhibition takes place. All products shown in the exhibitions are labelled with the amount of carbon dioxide (CO_2) stored in the product, which contributes to the reduction of CO_2 in the atmosphere and has a positive impact on the climate. This is very important in view of the current issue of climate change.

The *Charm of Wood* exhibition will be on display at eight other locations in Slovenia from May 21st to November 17th 2024.

Zgodba o stolu Sardan predstavljena na razstavi Čar lesa

The story of the Sardan chair presented at the exhibition the Charm of Wood

Borut Ovsenek*

Slika 1. Stol Sardan, Brest Cerknica. V marcu 1967 so prodali milijonti kos stola Sardan, ki je izstopal po kakovosti ter prodanih količinah (Brestov obzornik, 1967).

Figure 1. Sardan chair, Brest Cerknica. In March 1967 the one millionth Sardan chair was sold, a model that stood out for both its quality and the quantities sold (Brestov obzornik, 1967).

Stol Sardan so izdelovali v več pohištvenih tovarnah v Slovenji v šestdesetih letih 20. stoletja. Stol se je uporabljal kot jedilniški stol v kombinaciji s kotno klopjo in jedilno mizo, pa tudi v pisarnah, zadružnih domovih, šolah, gostinskih obratih itd. Ta stol je bil zelo popularen zaradi svojega oblikovanja, udobnosti, odlične konstrukcije in nizke cene. V Sloveniji pa tudi v drugih republikah Jugoslavije ga je imela doma skoraj vsaka družina. Stol Sardan se je izdeloval v velikih količinah v več različnih slovenskih tovarnah. Samo v tovarni Brest so na primer leta 1967 izdelali milijonti stol Sardan (slika 1).

Stol ima izredno dobro konstrukcijo, čeprav je zelo lahek. Lahko ga dvignemo z mezincem ene roke; kljub temu pa je ob vsakodnevni rabi lahko dočakal starost in ostal funkcionalen najmanj 60 let, tako kot primerek na sliki 2, ki so ga predstavili na razstavi Čar lesa 2024 v Cankarjevem domu v Ljubljani.

Stol Sardan je izdelan iz bukovega lesa, ki je v Sloveniji najbolj razširjen in široko uporaben les, in je glede na nizko ceno ter visoko trdnost in ugodne lastnosti najbolj primeren za ta tip stola. Stol je bil oblazinjen z umetnim usnjem–skajem, kar je omogočalo enostavno čiščenje in trpežnost.

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Ko je avtor tega prispevka Borut Ovsenek, dipl. inž. les., opazil star stol v sosedovi garaži, je prišel na idejo, da bi ta lepi stol spet obudili iz pozabe in ga ponovno ponudili na trgu. S proizvajalcem stolov L.ask d.o.o. iz Borovnice se je dogovoril za izdelavo prototipa in ga ponudil svojemu dolgoletnemu japonskemu partnerju, uvozniku in trgovcu s pohištvom. Preteklo je kar nekaj časa, da so detajle stola uskladili z željami japonskega tržišča. Treba ga je

Slika 2. Borut Ovsenek, dipl. inž. les., z razstavljenim originalnim stolom Sardan na razstavi Čar lesa v Cankarjevem domu maja 2024. Originalni stol Sardan, star nad 60 let, ki so ga izdelali v tovarni Brest Cerknica (desno), ter posodobljena verzija oz. replika Sardan Japonska (levo), ki ga njegova firma Eurasia trade že več let izvaža na Japonsko.
Figure 2. Borut Ovsenek, Dipl. Ing. at the exhibition the *Charm of Wood* at Cankarjev dom in Ljubljana in May 2024.The original Sardan chair, over 60 years old, made in the Brest Cerknica factory (right), and the modern replica the Sardan Japan (left), which his company Eurasia trade has been exporting to Japan for several years.

bilo ojačati, zaradi uporabe pri opremljanju objektov kot so kavarne, jedilnice, restavracije, hoteli in podobno. Spremeniti so morali določene detajle in prilagoditi višino sedeža, nakar se je leta 2014 prvič pojavil v katalogu japonskega kupca (slika 3).

Stol pošiljajo na Japonsko s kontejnerji. Stoli so montirani, surovi in pripravljeni za oblazinjenje, japonski kupec pa jih dokonča, polakira in oblazini glede na projekt ali ambient, kjer nameravajo stole uporabljati.

Na razstavi so prikazali »originalen« stol Sardan, ki je star vsaj 60 let, kot pravi njegova 93-letna lastnica. Poleg nje stol uporablja že četrta generacija. Razstavili so tudi stol-repliko, tak kot ga izvaža avtorjeva firma Eurasia trade na Japonsko že vrsto let. Razstavljeni vzorec je bil izdelan v maju 2024.

Ob obeh stolih je bila na panoju predstavljena celotna zgodba o stolu Sardan. Predstavljene so

Slika 3. Stol Sardan Japonska v katalogu japonskega trgovca.
Figure 3. The Sardan Japan in the Japanese retailer's catalogue.

bile kopije izrezkov iz Brestovega glasila Obzornik iz leta 1967, s fotografijo milijontega stola, izdelanega v Brestu, načrti in fotografije pa so nastale pri razvoju prototipa.

Prikazana je bila tudi uporaba stola Sardan na Japonskem s fotografijami iz kataloga, različnih projektov in ambientov, kjer je bil stol Sardan uporabljen.

The story of the Sardan chair was presented in May 2024 in the exhibition the *Charm of Wood* in Cankarjev dom in Ljubljana, Slovenia. The original Sardan chair, made of beech wood and usually made with a faux leather seat, was designed and manufactured in the Brest Cerknica factory, which also produced the chair in large quantities in the 1960s. The one millionth Sardan chair was sold in March 1967, with the model known for its high quality, good design and high sales (Brest Obzornik, 1967).

Years after production of the chair was discontinued in Brest Cerknica, the author of this article came up with the idea of bringing this beautiful chair back into production and offering it on the market. He reached an agreement with the chair manufacturer L.ask d.o.o. from Borovnica, Slovenia to build a new prototype, and offered it to his long-standing partner, an importer and furniture dealer in Japan. The new chair was modified in some design details and first appeared in the Japanese retailer's catalogue in 2014. Since then, it has been successfully sold in Japan for various purposes.

The *Charm of Wood* exhibition presented both an original Sardan chair made in Brest Cerknica, now over 60 years old, and a new, replica Sardan Japan. The updated chair has been exported to Japan by the company Eurasia trade.

VIR
REFERENCE

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Alumni lesarstva na obisku v Mizarskem muzeju Solkan

Alumni of Wood Science and Technology visited the Solkan carpentry museum

Darinka Kozinc*

Generacija alumen in alumnov univerzitetnega študija lesarstva iz celotne Slovenije, ki je študij lesarstva na Biotehniški fakulteti v Ljubljani vpisala v študijskem letu 1972/73 (slika 1), se redno sestaja. V januarju 2024 so bili povabljeni v Solkan (slika 2). Za organizacijo srečanja so bili zadolženi nekdanji primorski študentje in študentke.

Kot zbirno mesto je bil določen Mizarski muzej v Solkanu, kjer je 19 obiskovalcev pričakal Joško Markič, nekdanji direktor Mebla Top. Najprej so si ogledali staro mizarsko delavnico v pritličju, največ zanimanja pa je bilo deležno razstavljeno pohištvo v zgornjem nadstropju, zlasti duplikat Titovega kabineta, ki so ga izdelali solkanski mizarji. Rezljano pohištvo se je pred tem nahajalo v pisarni generalnega direktorja Mebla. Po razpadu tovarne pohištva Meblo je z odkupom Mestna občina Nova Gorica obogatila zbirko Goriškega muzeja.

Udeleženke in udeleženci so si ogledali tudi multimedijsko predstavitev mizarstva, zbirko lesa in nekaterih zanimivih izdelkov. Nekatere med njimi so izdelali dijaki Šolskega centra Nova Gorica: Strojne, lesarske in prometne šole.

Po ogledu je sledilo družabno srečanje v gostinskem lokalu Primula, nekdanji postaji žičnice, s pogledom na solkanski most. Pogovor med lesarskimi inženirkami in inženirji se je vrtel okrog privatizacijskega obdobja in propada nekdaj cvetoče lesne industrije. Večina se jih je po diplomi namreč zaposlila v različnih lesarskih podjetjih Meblo, Brest, Javor, Lipa, Garant, Lip Bled, Kli Logatec, Lesna Slovenj Gradec, Stol Kamnik. Večinoma so bili tudi njihove štipendistke in štipendisti, kjer so praviloma zasedali vodilna delovna mesta. Po bolečih stečajih so posameznice in posamezniki iskali lastne poslovne

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poti. Nekateri so se že prej zaposlili v strokovnem šolstvu, diplomaciji, na univerzi in carini. Tisti, ki se ukvarjajo s podjetništvom, so zelo uspešni, generacija se ponaša s »kraljem hrasta«, ki je uspel pretežno v Nemčiji in Avstriji.

Druženje je minilo v prijetnem vzdušju, k čemur je prispevalo tudi okolje; poleg obujanja spominov je potekalo tudi mreženje in sklepanje novih poslovnih sodelovanj.

Slovo je bilo prisrčno, z obljubo, da se naslednjič srečajo v centru Slovenije.

The generation of alumni of wood science and technology who started their studies at the Biotechnical Faculty in Ljubljana in the academic year 1972/73, and comes from all over Slovenia, meets regularly. In January 2024 they were invited to Solkan, Slovenia. The professional part of the visit took place at the Solkan Carpentry Museum, where the 19 visitors were welcomed by Joško Markič, former director of Meblo Top factory. The official, professional part of the trip was followed by informal socialising.

Slika 1. Študentke in študenti 4. letnika univerzitetnega študija lesarstva na terenskih vajah v Ribnici na Pohorju maja 1976.
Figure 1. Fourth-year students of wood science and technology on a field exercise in Ribnica na Pohorju in May 1976.

Slika 2. Alumne in alumni lesarstva na obisku v Mizarskem muzeju Solkan januarja 2024.
Figure 2. Wood science and technology alumni visiting the Solkan Carpentry Museum in January 2024.

Davor Kržišnik prejemnik nagrade za najbolj inovativno predstavitev na mednarodni konferenci o zaščiti lesa

Davor Kržišnik received the Viance Innovation Award at the International Research Group on Wood Protection Conference

Teja Bizjak Govedič

Konec maja 2024 je Mednarodna raziskovalna skupina za zaščito lesa (International Research Group on Wood Protection) v Knoxvillu, ZDA, organizirala že 55. konferenco o zaščiti lesa. Organizacija s približno 330 člani iz 50 držav, vključno s Slovenijo, vsako leto priredi konferenco, na kateri se zvrsti med 100 in 200 prispevkov. Na letošnji konferenci je nagrado »Viance innovation award«, ki jo podeljuje podjetje Viance za najbolj inovativno predstavitev, med 87 predstavitvami prejel doc. dr. Davor Kržišnik z Univerze v Ljubljani, Biotehniške fakultete, Oddelka za lesarstvo.

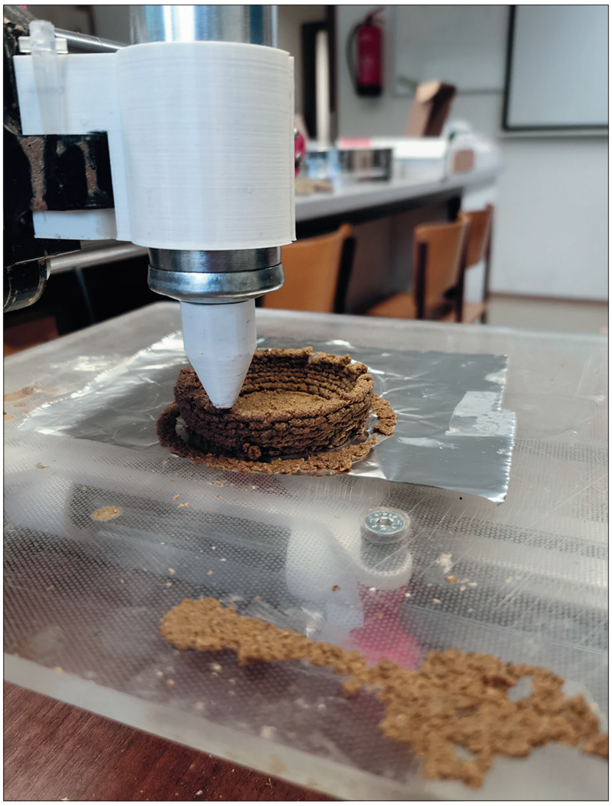
Doc. dr. Davor Kržišnik je na srečanju predstavil izsledke raziskave, ki je nastala pod njegovim mentorstvom in somentorstvom doc. dr. Mirka Kariža, v okviru diplomskega dela, ki ga je pripravil študent Blaž Žuran. V raziskavi so razvijali nove materiale, ki omogočajo 3D tisk z uporabo glivnega micelija. Industrija 3D tiska se namreč sooča z vse večjo potrebo po uporabi alternativnih, biorazgradljivih materialov iz obnovljivih virov. V raziskavi so preizkusili materiale, ki temeljijo na trajnostni rabi urbanih ostankov, kot so pivske tropine, otrobi, lesni peleti in odslužena kavna usedlina. Kot vezivo so uporabili glivni micelij, ki omogoča preprosto razgradnjo materialov ob koncu življenjskega cikla izdelka. Nastali kompoziti so obetavni predvsem za trajnostno embalažo, izolacijo in podobne produkte.

V seriji laboratorijskih poskusov so najprej preverili, kateri substrat je najprimernejši za rast gliv. Nato so pripravili različne paste za 3D tisk in na koncu izvedli 3D tisk izdelka z najustreznejšo pasto. Ta pasta je morala imeti primerno viskoznost in vsebovati ustrezno majhne delce, da je bil tisk mogoč. Poleg tega je njena sestava morala zagotavljati, da natisnjen izdelek obdrži želeno obliko.

Po uspešno natisnjenem izdelku je micelij v rastni komori izdelek prerastel v približno desetih dneh. Lastnosti izdelka, ki je bil po inkubaciji v rastni komori posušen na 60 °C, so bile več kot zadovoljive. Obdržal je želeno obliko skodelice in bil dovolj kompakten, kar dokazuje, da je tisk s takim materialom mogoč in da so nadaljnje raziskave na tem področju zelo obetavne.

Slika 1. Podelitev nagrade (od leve proti desni): dr. Rod Stirling, predsednik IRG, nagrajenec dr. Davor Kržišnik in dr. Kevin Archer, direktor raziskav in razvoja v podjetju Viance (Foto: dr. Dennis Jones).

Figure 1. The award ceremony (from left to right): Dr Rod Stirling, President of the IRG, Dr Davor Kržišnik, the recipient of the award and Dr Kevin Archer, Director of Research and Development at Vinace (Photo: Dr Dennis Jones).



Slika 2. 3D tiskanje s pasto iz mešanice substrata, glivnega inokuluma in sredstva za želiranje, v tem primeru koruznega škroba (Foto: Blaž Žuran).
Figure 2. 3D printing with a paste made from a mixture of substrate, fungal inoculum and a gelling agent, in this case cornstarch (Photo: Blaž Žuran).

At the end of May 2024, the International Research Group on Wood Protection held its 55th conference in Knoxville, USA. The organization has around 330 members from 50 countries, including Slovenia. The IRG's scientific conferences are held annually and are attended by between 200 and 360 participants. Between 100 and 200 lectures and poster presentations are given at the annual conference each year. At this year's conference, the Viance Innovation Award for the most innovative out of 87 presentations was awarded to Assistant Prof. Dr Davor Kržišnik from the University of Ljubljana, Biotechnical Faculty, Department of Wood Science and Technology.

At the meeting, Dr Davor Kržišnik presented the results of research carried out under his mentorship and the co-mentorship of Assistant Prof. Dr Mirko Kariž, as part of Blaž Žuran's diploma thesis. In their research, they developed new materials that enable 3D printing with the help of fungal mycelia. This is because the 3D printing industry is facing a growing demand to use alternative, biodegradable materials from renewable sources. As part of the awarded research a number of materials were tested that are produced based on the sustainable use of urban waste, such as brewer's grain, wheat bran, wood pellets and used coffee grounds. Fungal mycelium was used as a binder, which enabled easy decomposition of the materials at the

Slika 3. Natisnjena posodica pred preraščanjem z micelijem (levo) in po preraščanju (desno) (Foto: Blaž Žuran).
Figure 3. 3D-printed pot before fungal overgrowth with mycelium (on the left) and after overgrowth (on the right) (Photo: Blaž Žuran).

end of the product's life cycle. Composite materials of this type are particularly promising for sustainable packaging, insulation and similar uses.

In a series of laboratory experiments, it was first identified which substrate was best suited for the growth of fungi. Afterwards various pastes for 3D printing were prepared, and finally the product was 3D printed with the most suitable paste. This paste had to have an appropriate viscosity and contain sufficiently small particles for printing to be possible. In addition, the composition had to ensure that the printed product retained the desired shape.

Once the product had been successfully printed, the mycelium in the growth chamber outgrew the product within around ten days. The properties of the product, which was dried at 60°C after incubation in the growth chamber, were more than satisfactory. It retained the desired shape of the cup and was compact enough, proving that printing with such a material is possible and that further research in this area is very promising. •

Zlati medalji za raziskovalno nalogo dijakov Gimnazije Vič v sodelovanju z Oddelkom za lesarstvo UL BF

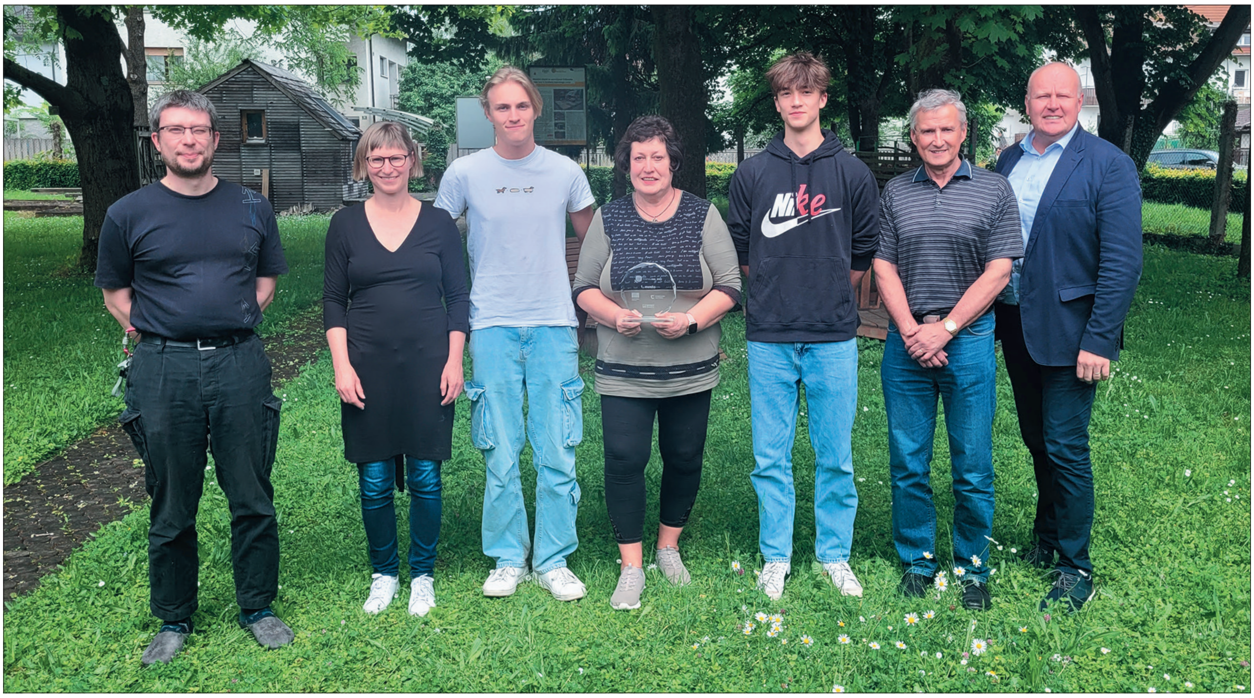
Gold medals for a research project by students of Gymnazija Vič in cooperation with the Department of Wood Science and Technology, UL BF

Marko Petrič

Dijakinje in dijaki ljubljanske Gimnazije Vič v laboratorijih Oddelka za lesarstvo Biotehniške fakultete Univerze v Ljubljani (OL BF UL) skoraj vsako leto izvajajo najrazličnejše poskuse za svoje dijaške raziskovalne naloge. Tako smo na Oddelku za lesarstvo z bližnjo Gimnazijo Vič razvili odlično dolgoletno sodelovanje. Dijakinjam in dijakom pomagamo na različne načine, npr. tako, da skupaj sooblikujemo temo in vsebino raziskovalne naloge, sodelavke in sodelavci Oddelka smo somentorice oz. somentorji, naše tehnično osebje jim pomaga pri izvedbi poskusov, seznanimo jih z zahtevnimi instrumentalnimi metodami, ipd. Odlično sodelovanje pri pripravi dijaških raziskovalnih nalog se je začelo in razvilo na pobudo prof. Alenke Mozer, ki na Gimnaziji Vič poučuje kemijo in biologijo. Prof. Mozer z veliko energije in navdušenja že dolga leta svoje dijakinje in dijake uvaja v skrivnosti raziskovalnega dela in je pri tem izjemno uspešna, saj dijakinje in dijaki s svojimi raziskovalnimi nalogami na domačih in mednarodnih tekmovanjih po vsem svetu redno posegajo po najvišjih, neredko tudi prvih mestih.

Letos sta se dijaka Peter Podjed in Črt Stepišnik z Gimnazije Vič v sodelovanju z OL BF odločila raziskati možnosti uporabe lignina za izdelavo okolju prijaznih lepil za les. Dijaka sta izvedla mikroaerobno fermentacijo industrijskega lignina in dokazala, da je tako depolimeriziran lignin možno uspešno uporabiti kot lepilo za les. Raziskovalno nalogo sta pripravila pod mentorskim vodstvom prof. Alenke Mozer z Gimnazije Vič in somentorstvom dr. Nade Verdel iz podjetja Fenolit v Borovnici. Na OL BF smo dijakoma pomagali prof. dr. Milan Šernek, doc. dr. Sebastian Dahle, prof. dr. Marko Petrič, prof. dr. Sergej Medved in Samo Grbec. Dijaka Peter in Črt sta opravila odlično delo, saj sta z raziskovalno nalogo »Depolymerization of Lignin by Fermentation« (»Depolimerizacija lignina s fermentacijo«) na tekmovanju VILIPO – Vilnius International Project Olympiad, v Vilni v Litvi in na tekmovanju tržnih znanstvenih srednješolskih projektov ScienceJam v Novem mestu, dosegla velik uspeh. Na obeh tekmovanjih sta prejela zlati medalji!

Raziskovalno delo dijakinj in dijakov na Oddelku za lesarstvo je vsekakor izjemno koristno, ker se pri tem spoznajo z resnim raziskovalnim delom ter se lažje odločijo za to, kaj bodo študirali in kakšna bo njihova poklicna pot. Seveda pa smo takega sodelovanja izjemno veseli tudi sodelavke in sodelavci Oddelka. To je eden najboljših možnih načinov promocije lesa kot trajnostnega in okolju prijaznega materiala, hkrati pa se povečajo možnosti, da mladi srednješolski raziskovalci spoznajo velik potencial študija lesarstva.



Slika 1. Nagrajenca in mentorji na zelenici pred Oddelkom za lesarstvo (od leve proti desni): doc. dr. Sebastian Dahle, dr. Nada Verdel, nagrajenec Peter Podjed, prof. Alenka Mozer, nagrajenec Črt Stepišnik, prof. dr. Marko Petrič in prof. dr. Milan Šernek (Foto: Olga Marko).

Figure 1. The award winners and mentors on the lawn in front of the Department of Wood Science and Technology, Biotechnical Faculty, University of Ljubljana (from left to right): Assoc. Prof. Dr Sebastian Dahle, Dr Nada Verdel, award winner Peter Podjed, Prof. Alenka Mozer, award winner Črt Stepišnik, Prof. Dr Marko Petrič and Prof. Dr Milan Šernek (Photo: Olga Marko).

Almost every year, students from the secondary school Gimnazija Vič, Ljubljana, Slovenia, carry out various experiments in the laboratories of the Department of Wood Science and Technology of the Biotechnical Faculty, University of Ljubljana (DWST BF UL) as part of their research assignments. DWST and the nearby Gimnazija Vič have been working together for many years. At DWST, we help students develop the topic and content of the research, and DWST professors act as co-mentors. Among other things, the technical staff help with experiments and provide instructions on how to use the complex instrumental methods. The excellent collaboration began several years ago on the initiative of Prof. Alenka Mozer, who teaches chemistry and biology at Gimnazija Vič. Prof. Mozer has been introducing students to the secrets of research work with great enthusiasm and success for many years. Students regularly win top places, often even first prizes, in national and international research competitions all over the world.

This year, Peter Podjed and Črt Stepišnik from Gimnazija Vič, in cooperation with DWST, decided to investigate the possibilities of using lignin to produce environmentally friendly wood glues. The students carried out a microaerobic fermentation of industrial lignin and showed that this depolymerised lignin can be successfully used as wood glue. The research was conducted under the supervision of Prof. Alenka Mozer from Gimnazija Vič and the co-mentorship of Dr Nada Verdel from Fenolit Borovnica. At DWST, the students were supported by Prof. Dr Milan Šernek, Assoc. Prof. Dr Sebastian Dahle, Prof. Dr Marko Petrič, Prof. Dr Sergej Medved and Samo Grbec. The students Peter and Črt did an outstanding job with their research project "Depolymerization of Lignin by Fermentation" at the VILIPO – Vilnius International Project Olympiad, in Lithuania, and at the ScienceJam competition for marketable scientific projects of high schools in Novo mesto, Slovenia. They won gold medals in both competitions!