

The durability, chemical and mechanical properties of 40 years old black locust posts

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ABSTRACT

This study investigated the performance of 40-year-old black locust (*Robinia pseudoacacia*) posts, previously employed in a vineyard. Wood from these posts was compared with wood from recently harvested wood to assess their potential for reuse. Visual inspection, hyperspectral imaging, chemical analysis and laboratory tests were utilised to evaluate decay, density, mechanical properties and extractive content. The older posts exhibited superior mechanical properties compared to the newly harvested wood. The older posts noted a higher density, indicating their superior quality. The heartwood of old black locust posts contained more extractives and phenolic compounds than the recently harvested wood. Minimal decay was revealed, classifying the wood into durability classes 1 or 2. No difference was observed in the inherent durability between the older and recent wood. The findings of this research demonstrate that 40-year-old black locust posts maintain exceptional durability and mechanical properties, rendering them suitable for reuse in outdoor applications.

1. Introduction

Wooden posts play a crucial role in many agricultural operations, with a traditional application being in vineyards, where they support the growth of grapevines. In such cases, wood is exposed to harsh conditions that are defined as “use class 4 (ground contact)” by EN 335 [1]. Use class 4 wood is exposed to degradation factors, including fungal, bacterial and insect attack, as well as UV degradation and rain [2]. Wood species of low durability are thus not suited for these applications; therefore, support posts were traditionally made of durable wood species or wood treated with biocides [3]. In Slovenia, or Europe in general, most native wood species are not durable enough to be used in “use class 4” conditions. Two notable native wood species at a commercially important scale are English Oak (*Quercus sp.*) and Sweet chestnut (*Castanea sativa* Mill.) [4]. Standard EN 350 classifies Sweet chestnut into durability classes 1–2, while oak heartwood is classified into durability classes 2–4, indicating its significant variability in durability [5, 6]. Although numerous durability and material performance studies have been conducted on recently harvested wood, there is limited data available on the durability and material performance of wood that has been in use for several decades. Properties of the used material are of considerable importance for safe reuse to achieve the target service life and to limit potential damage.

The black locust (*Robinia pseudoacacia* L.) was first introduced to Europe in the 17th century. The pioneer black locust trees were planted in the King of France’s garden in 1635, predominantly due to spring flowering. It has several English names, such as false acacia, locust, black locust and Robinia. It is the earliest North American tree species introduced to Europe [7].

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The tree has become extensively naturalised in continental Europe and was commonly used around railway tracks to prevent erosion and landslides. Its rapid spread across Europe was aided by rail traffic, which helped ferry the seeds long distances. Due to its utility, it is also a tree species that is widely cultivated on plantations which cover considerable swathes of land, notably in Hungary (275,000 ha), Romania (191,000 ha), former USSR (144,000 ha), France (100,000 ha), Bulgaria (73,000 ha), and Republic of Croatia (50,000 ha) [8]. Its spread outside its native range was not limited to Europe, as it is now common in many parts of the world's temperate regions. The native range of black locust, however, is limited to the Appalachian Mountains and Arkansas, Missouri, and Oklahoma [3]. Black locust is a common pioneering species, which is attributed to its symbiosis with bacteria from the genus *Rhizobium*, which helps trees use nitrogen.

Black locust has ring-porous wood, and its density is proportional to the annual growth ring width [9]. During years with optimal growing conditions, black locusts yield wood with a high density due to the higher proportion of libriform fibres in the latewood. Conversely, poor growing conditions result in small annual growth ring increments, where the proportion of large vessels in the early wood causes a lower overall density of the wood. The relative strength of the wood and its hardness are in direct correlation with its density [7,10]. The durability of black locust wood was established early on and was one of the reasons behind its spread across continental Europe. We have discovered that its durability mainly stems from its ability to exclude water and the presence of biologically active secondary metabolites- commonly referred to as extractives in its heartwood [11–13]. The relative service life of black locust was determined to be 10.8 times longer than of the reference wood of Norway spruce (*Picea abies* (L.) H. Karst.) as determined by laboratory and field trials [14]. Recent research, however, shows that a significant degree of variability can be observed in the biological durability of black locust wood. For example, black locust wood from many places, including the US, was categorised as Durability Class 1, indicating high durability; wood from Germany fell into Durability Classes 2 and 3, suggesting lower durability. Similarly, wood from Romania and Slovenia was placed in Durability Class 2 as defined by the EN 350 standard [15]. These variations in durability are likely due to differences in the wood's origin and the specific extractive contents found in the wood from these locations [8].

An essential element contributing to the durability of black locust wood is the composition and concentration of its biologically active phenolic compounds. In addition to phenolic compounds, numerous other extractable compounds can be found in black locust wood, ranging from triterpenes, simple sugars (glucose, sucrose, fructose), non-structural carbohydrates like starch, and some soluble proteins [16,17]. The composition of phenolic substances is diverse and can include simple phenols, stilbenes, flavonoids, phenolic acids, and condensed tannins [18]. Notably, flavonoids such as dihydrorobinetin, robinetin, and derivatives of hydroxycinnamic acid are distinctive phenolic compounds found in the hydrophilic extracts, i.e. when black locust heartwood is extracted with ethanol, methanol, acetone or water [16,17]. Bioactive polyphenols with robinetins contribute significantly to the black locust wood's natural resistance to decay [16,17]. The majority of the studies so far have been performed on the recently harvested wood. These

Wooden posts in vineyards should last as long as or longer than the vineyards themselves. The expected service life of the vineyards is between 30 and 40 years [19]. Therefore, black locust posts may outlast the typical vineyard lifespan, raising questions about their potential for reuse. As there could be around 10000 posts/ha of vineyard, the question for the vineyard owners arises whether the respective posts could be reused or repurposed [20]. The importance of recycling and reuse in the building sector [21,22] as well as in the local communities [23] has been addressed already. Still, the circularity principles have not been fully utilised in the wooden objects in the agricultural sector. Current waste strategies in the EU prescribe that reuse and recycling are favoured over energy recovery or disposal [24]. Thus, for this study, approximately 40-year-old black locust posts from a restored vineyard was sourced. The respective manuscript aimed to compare key properties of the 40-year-old black locust posts with reference posts, made of recently harvested black locust from the exact location, to study the variations in durability and other key properties. The objective was to determine if the old posts can be reused in the vineyard and if we can specify a sufficient service life for them, or if new ones from virgin wood need to be prepared.

2. Materials and methods

Black locust posts were obtained from a renovated 40-year-old vineyard in the village of Slap, in the Vipava Valley, Slovenia (45.83989561280445, 13.933703865564372) at an altitude of 132 m. The Vipava Valley experiences a warm summer climate classified as Marine West Coast (Cfb). The average annual temperature in this region is 11.56 °C. The area typically receives about 1551 mm of precipitation and has, on average, 140 rainy days annually [25].

Sixty posts were inspected on site, and decay depth was determined according to EN 252 [26]. Decay was assessed in four locations: in soil (up to 30 cm deep), the soil/air transition zone, the middle, and the top of the posts. Six randomly selected posts were sampled and brought to the laboratory. In addition, three reference posts (freshly cut) were collected from the same forest in the vicinity of the vineyard, where the old ones were harvested as well. Each of the posts originated from a different tree. The length of the posts varied between 2.5 m and 2.6 m. The diameter of posts varied between 10 cm and 15 cm.

The cross-sections of the old posts were analysed using a Clyde HSI SC-A3 translation series hyperspectral scanning system in the shortwave infrared (SWIR) range (1000 – 2500 nm), and the decay was mapped using principal component analysis (PCA).

The posts were air-dried and divided into three parts: lower (GP), middle (MP), and top part (TP), and the six posts were numbered from 1 to 6. The reference posts, which were freshly cut (7–9), were not divided and considered a homogeneous group, as they came from the same area, had comparable diameters, and were of similar age. Visual appearance, density and ring width confirmed this presumption. Reference posts were prepared to be used in the respective vineyard, but were randomly selected to be examined within the respective study. As the main objective of the respective manuscript is to compare the old and reference posts, thus the variability within the reference posts was not studied. For all of the tests, only heartwood was considered. At old posts, sapwood was degraded,

while we removed the sapwood at reference (freshly cut) ones. We did not distinguish between the adult and juvenile wood. The majority of the wood was juvenile anyhow. Four sets of samples were prepared (Fig. 1):

- A: Cross-section of the posts
- B: Samples for durability and wetting ability assessment ($1.5 \text{ cm} \times 2.5 \text{ cm} \times 5.0 \text{ cm}$)
- C: Samples for assessment of bending strength ($0.5 \text{ cm} \times 1.0 \text{ cm} \times 10.0 \text{ cm}$)
- D: Residues were milled to sawdust for assessment of extractives.

Series B samples (20 per group) were conditioned at ambient laboratory conditions (22°C and 65 % relative humidity) for 8 weeks before their density was determined gravimetrically. The moisture content of the wood varied between 11.4 % and 12.3 %. Samples C (10 per group) were conditioned at ambient laboratory conditions before conducting three-point bending tests. A Zwick universal testing machine Z005 (Zwick-Roell, Germany) was employed to measure the modulus of elasticity in accordance with EN 310 [27].

The sawing residue was used for the chemical analysis and determination of extractives content and their composition. Extractives were obtained from the wood samples using an ASE 350 accelerated extraction system (Thermo Fisher Scientific Inc., Waltham, US). The solvent used was a mixture of acetone and water, in a ratio of 90:10 (v/v). Acetone: water mixture (90:10 v/v) was deemed optimal for the extraction of hydrophilic extractives of black locust heartwood based on previous research [28]. Before extraction, the wood samples were ground to a powder with particles smaller than 1 mm and dried for 24 h at $60 \pm 1^\circ\text{C}$. The moisture content of all samples analysed for the chemistry of the extractives was therefore reduced to below 8 % to avoid undesirable biochemical changes and thus the degradation of the native polyphenols. The dried, ground wood was weighed and loaded into a 10 mL stainless steel extraction cell with a cellulose filter. Wood extractions were performed under a nitrogen atmosphere at 10.34214 MPa and 110°C with $4 \times 5 \text{ min}$ static extraction cycles. The wood extracts were thus filtered online during the extraction process on the ASE system. All wood extracts obtained were prepared in such a way that a sample-to-solvent ratio of 1:100 (w/v) was achieved. Following extraction, the mass loss was documented, and the total wood extractive content (TEC) and total wood phenolic content (TPC) were computed based on established methods [17,28]. TEC was measured by drying 10 mL of black locust extract to a constant mass and weighing it. TEC were expressed in grams per gram of wood sample (mg/g dw). Further analysis of total TPC was performed calorimetrically using the modified Folin-Ciocalteu method [29]. Wood extracts were treated with Folin-Ciocalteu reagent and sodium carbonate, then incubated at room temperature for 120 min. Absorbance was measured at 765 nm. TPC was calculated and expressed as gallic acid equivalents per dried wood sample (mg GAE/g dw). The colourimetric method was linear within the selected concentration range ($R^2 < 0.99$) [16].

The Meyer-Veltrup methodology [12,30] was applied to determine the wood inherent durability (k_{inh}) and wood wetting ability (k_{wa}) factors of the tested black locust wood specimens. The methodology has been described in depth in previous publications from our group [30]. The factors used are described in Table 1. Briefly, the k_{inh} is determined on samples measuring $15 \times 25 \times 50 \text{ mm}$, which are subject to fungal decay in compliance with EN 113 [31] using two white rot causing fungi (*Trametes versicolor* (L.) Lloyd and *Hypoxylon fragiforme* (Pers.) J.Kickx f) and a single brown rot wood degrading fungus (*Gloeophyllum trabeum* (Pers.) Murrill). The specimens were exposed for 16 weeks at 25°C and 85 % relative air humidity. After 16 weeks, the samples were cleaned, dried to constant mass at $103 \pm 2^\circ\text{C}$ and the mass losses recorded. In parallel to the black locust, control specimens consisting of European beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies*) were also exposed to the same fungi to act as virulence controls for the selected fungi.

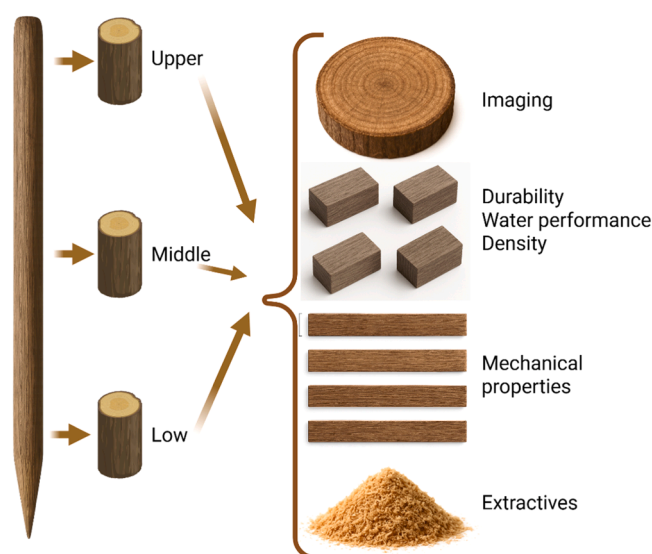


Fig. 1. Schematic representation of the experiment. Created in BioRender. Humar, M. (2025) <https://BioRender.com/ar2hnm5>.

Table 1

Description of key indicators addressed in the respective article.

Indicator	Description
k_{wa}	The wetting ability of wood-based materials is described in relation to that of spruce wood.
k_{inh}	Wood-based materials' inherent durability is quantified in relation to that of spruce wood.
d_{Rd}	The resistance dose reflects the material properties, measured in days (d) under optimal wood moisture and temperature conditions for fungal decay before any decay is observed.
Rel. d_{Rd}	Typical resistance dose. Spruce is often employed as the normalisation factor.

To determine the k_{wa} factors, additional water uptake and sorption testing were done on the same-sized samples as for the k_{inh} factor determination. Briefly, five samples per each location on each individual post were used for sorption testing and five per location and post for liquid water uptake. Sorption testing was done in a climate chamber with a relative air humidity approaching 100 %. The wood samples were oven-dried at 60 °C for 24 h before the test, and their mass was recorded. After exposure to the high-humidity environment, their mass was recorded after 24 h and after 3 weeks of total conditioning time. Desorption was assessed by drying the samples over silica with forced air flow. Liquid water uptake was done via short-term capillary absorption using a K100MK2 Tensiometer (Krüss Scientific, Germany). Before the test, the samples were conditioned to a constant mass at 20 °C and 65 % relative humidity. The capillary water uptake was recorded for 200 s. Furthermore, long-term water uptake, over 24 h, was done according to ENV-1250-2 [32]. Before respective testing, wood samples were dried to constant mass (60 ± 2 °C). Each wood block was then submerged in a beaker containing 100 g of deionised water and weighed down to prevent floating. The final wood moisture content was determined using the mass difference, which was the total absorbed water over 24 h.

Differences between statistical groups were analysed using ANOVA (Fisher's LSD) at a 95 % confidence level. The main objective was to analyse differences between old and reference posts; thus, we focus on this comparison.

The accumulated data from these moisture tests were integral to a modelling approach that predicted the field performance of the materials. Using the Meyer-Veltrup model [12], wettability factors were calculated from the results of various tests and combined with inherent durability factors to calculate the resistance dose of the wood materials against climatic exposure. This approach aimed to quantify the resistance of the materials as a function of their physical properties and environmental resilience.

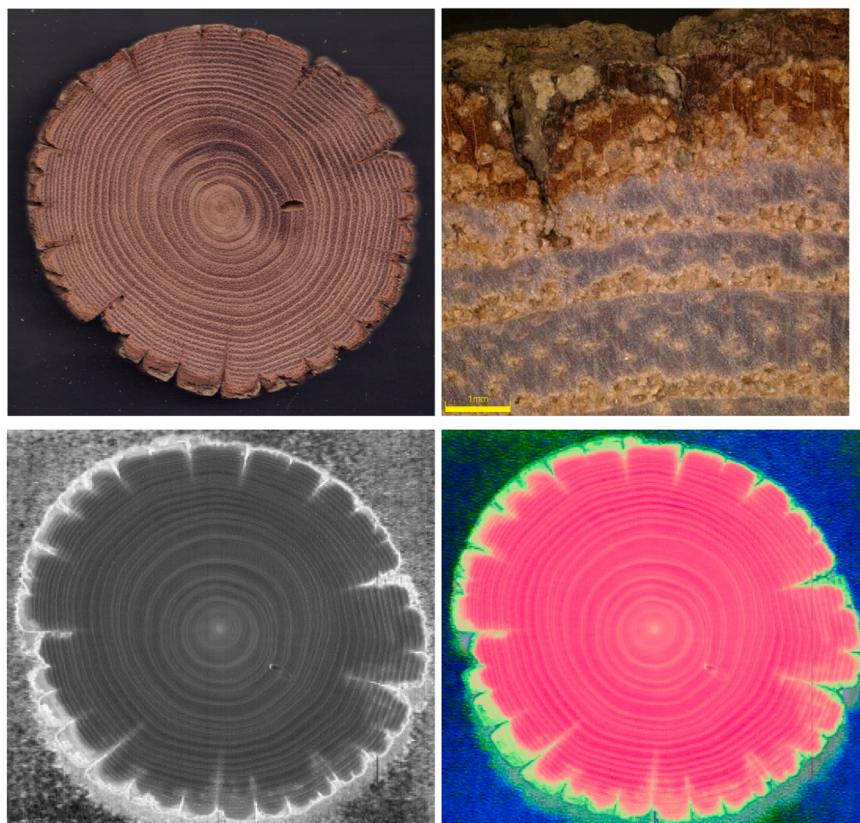


Fig. 2. Cross-section of post (upper left) and the outer degraded layer under the microscope (upper right) and degradation in the outer layers of black locust posts as determined by hyperspectral imaging using different indications (second row): The image in the second row displays the contribution of three principal components, PC1 represent 85 %, PC2 11 % and PC3 5 % of variation.

3. Results and discussion

3.1. Degradation of posts

Wooden posts removed from the vineyard were visually inspected on-site. With the help of a knife, the depth of the degraded layer was detected (Fig. 2). It should be considered that the posts were very likely installed with bark and sapwood present. This part of the wood tissue was fully degraded in 40 years, so only the heartwood remained. As can be seen from Fig. 3, the outer layer of the black locust posts was degraded. As the tyloses are present in the respective degraded layer, it can be presumed that the degraded layer is the heartwood. Sapwood of all wood species, including black locust, is very susceptible to decay and, thus, was likely decayed and eroded from the surface in the first years after application [6,15].

The thickness of the degradation layer varied based on the exposure of the post. The thickest layer was determined in the ground (1.9 mm), followed by the transition zone (1.3 mm), while the lowest degradation layer was determined at the middle and at the top (0.5 mm) (Fig. 3). This is in line with the use-class approach. Wood that is in contact with soil faces a higher risk of degradation compared to wood used in above-ground settings [33].

In addition to visual inspection, the post cross-sections were analysed with hyperspectral imaging to visualise the spread of the degraded wood. As can be resolved from the decay mapping (Fig. 2), the outer layer of the posts was degraded. This layer was 1–2 mm thick. The incipient signs of decay were visible approximately 1 cm below the surface. In addition, the cracks represent the entrance point for the decay. Moisture is trapped in the cracks; thus, the conditions for decay are more favourable than those of the nearby tissues [34].

3.2. Density and mechanical properties of wood

One of the key quality indicators of wood is density, especially in ring-porous species [5]. The analysed 40-year-old vineyard posts had an average density of 838 kg/m³, considerably higher than the 784 kg/m³ of the recently harvested posts from the exact location (Table 2). Data on density are at the upper end of the density range reported in the literature [10]. As recent and old posts originated from the same forests, where management practices have not changed in the past 50 years, and were of comparable dimensions with comparable portions of juvenile wood, it can be assumed that one of the reasons for the differences in density can be attributed to climate change. [35]. Additionally, the ring widths were comparable, ranging from 6 mm in the first years to 2 mm in the most recent rings. There were no significant differences in wood density regarding the position within the old posts. Differences between the upper, lower and middle sections were insignificant. This confirms that there was no significant fungal decay developed within the old posts, as degradation usually reflects in a lower density as well [36].

The high density of the material suggests improved mechanical properties. The modulus of elasticity (MoE) and bending strength (MoR) of the upper section (MoE - 18683 MPa) and middle section (MoE - 18168 MPa) of the posts were significantly higher compared to those of recent black locust wood (MoE—14740 MPa). These values are higher than the modulus elasticity reported in the literature for Black locust (9000 – 14.000 MPa) [7,10] indicating the old posts' high quality. The high modulus of elasticity (MoE) and bending strength modulus (MoR) align with the high wood density. In addition, high mechanical properties confirm the absence of decay, as the loss of mechanical properties is usually the first sign of fungal decay, before the mass loss or density change can be observed [37,38]. In addition, since the posts were not subjected to higher mechanical loadings, no fatigue was observed, which could potentially influence their mechanical properties as well [39]. However, slightly lower mechanical properties, but still comparable to reference materials (freshly cut posts), were determined at the lower part of the posts (MoE 16814 MPa) (Table 2). This is presumably the result of the incipient stages of degradation caused by the fungi, bacteria and other abiotic degradation factors, as indicated by hyperspectral images (Fig. 2). Hyperspectral images indicate the variations in density and chemical composition. Areas with lower density are

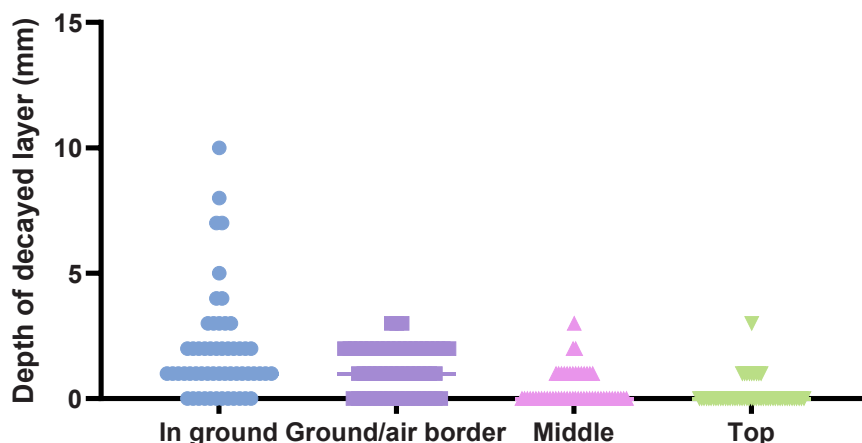


Fig. 3. Depth of the degraded layer on the analysed black locust posts (n = 60)- Width of the bars represents the frequency of the values.

Table 2

Density, mechanical characteristics, moisture levels, and decay indicators are utilised to assess factors that influence the service life of the wood. RH100 24 h – Water vapour absorption after 24 h, Release – water desorption after drying over silica gel, STWU – short-term water uptake measured with a tensiometer, MC 24 h – moisture content after 24 h of immersion, mass loss after exposure to fungi. DC is a durability classification as described by CEN/TS 15083–1. Different letters indicate statistically significant differences between groups at a confidence level of 95.0. Beech wood and spruce wood were not included in the comparison.

	Black locust				Spruce	Beech
	Low	Middle	Upper	Reference*		
Density (kg/m ³)	838 ^a	847 ^a	829 ^a	784 ^b	469	701
MoE (MPa)	16814 ^b	18168 ^a	18683 ^a	14740 ^c	11384	14650
MoR (N/mm ²)	191.0 ^b	204.3 ^a	210.4 ^a	178.2 ^c	94.3	118.6
Mass loss – Gt ^{**} (%)	0.7 ^a	0.7 ^a	0.7 ^a	0.4 ^a	59.3	62.7
Mass loss – Tv ^{***} (%)	3.1 ^b	5.1 ^a	2.6 ^a	2.4 ^a	17.8	44.6
Mass loss – Hf ^{****} (%)	4.0 ^a	3.6 ^a	4.0 ^a	6.2 ^b	20.0	42.7
Durability class	1	2	1	2	5	5
RH100 24 h (%)	5.2 ^b	5.4 ^b	5.7 ^b	9.5 ^a	10.2	11.6
Release (%)	7.3 ^b	7.2 ^b	7.4 ^b	7.9 ^a	8.4	7.9
STWU (g/cm ²)	0.0919 ^a	0.0849 ^b	0.0879 ^b	0.0870 ^b	0.1760	0.2584
MC 24 h (%)	15.4 ^b	15.1 ^b	15.8 ^b	17.4 ^a	55.2	65.4

* Heartwood sample from a freshly felled black locust tree (for further information, see description in Materials and Methods).

** Gt – Gloeophyllum trabeum

*** Tv – Trametes versicolor

**** Hf – Hypoxylon fragiforme

lighter, as evident from the lighter tones on the greyscale image or green tones on the coloured image. From this mapping, it can be resolved that the degradation is predominantly limited to the outer zone, which is the most exposed to the broad spectrum of degradation factors.

3.3. Chemical properties and durability of wood

Extractives play an important role in wood durability [40]. Extraction of the wood in the ASE system yielded significantly higher amounts of total extractives (TEC) and polyphenols (TPC) from the old black locust heartwood than from the heartwood samples of the recently felled trees (ANOVA, $p < 0.050$) (Table 3). The average values for the reference (Ref) sample (Table 3) were higher (7.42 % TEC and 4.66 % TPC, dw) compared to the results of TEC and TPC in the black locust heartwood of our previous study (6.2 % and 2.48 %, dw) [28], which can be explained by the more efficient subcritical extraction with the ASE system. Literature data indicates that extracting the heartwood from a black locust post using a Soxhlet apparatus with 90 % acetone (aq, v/v) can yield more than 9.0 % (dw) TEC and almost 5.0 % (dw) TPC [41]. In this regard, it can be concluded that the extraction yield of total extractives in polyphenols from reference samples of recently harvested black locust trees is consistent with the literature data [10,16].

Our chemical analysis clearly showed that the TEC and TPC in heartwood samples from old black locust posts were significantly higher than the extractives content in the reference sample of a recently harvested black locust (LSD test) (Table 3). On average, the ASE extracts of the old heartwood samples contained 27.59 % (w/w) more TEC and 25.16 % more TPC than the reference heartwood sample (Table 3). The high TEC and TPC values measured in the heartwood samples of old posts may not be exclusively due to the low molecular weight phenolic extractives and other non-structural extractives usually present in wood [42]. Other compounds might contribute to high extractive content, such as degradation products of lignin, including phenolic acids and aldehydes [43–45]. Predominantly, lignin degradation is based on the free radical-induced mechanisms, which result in the random depolymerisation of lignin, and formation of phenolic polymers and has been proven on grape wood and Scots pine (*Pinus sylvestris* L.) wood already [46, 47]. These compounds may contribute to the observed fungal resistance of aged black locust heartwood (Table 2), although their

Table 3

Moisture content (u) and extractives content (TEC and TPC) in samples of heartwood from black locust (*Robinia pseudoacacia*). TEC, total extractives content. TPC, total phenolic content. TPC/TEC ratio: percentage of polyphenols in the extracts obtained with the ASE 350 extraction system.

Sample*	u			TEC			TPC			TPC/TEC ratio		
	%, w/w			mg/g			mg/g			%, w/w		
	avg	sd	LSD**	avg	sd	LSD**	avg	sd	LSD**	avg	sd	LSD**
Ref***	6.00 %		a	74.21		c	46.59		b	62.78		a
GP	5.83 %	0.98 %	a	111.88	11.50	a	65.02	8.74	a	59.46	9.21	a
MP	6.67 %	1.03 %	a	103.01	11.41	ba	63.03	7.08	a	61.23	3.25	a
TP	6.50 %	0.55 %	a	92.57	8.54	cb	58.70	4.88	ba	63.48	1.73	a

* Position of the sample in a sampled post: Ref, reference as fresh heartwood sample of black locust; GP, wood samples from the post in the ground; MP, wood samples from the middle of the post; TP, wood samples from the top of the post.

** Results of a Fisher's least significant difference (LSD) test at a confidence level of 95.0.

*** Heartwood sample from a reference, freshly felled black locust tree (for further information, see description in Materials and Methods).

individual bioactivity was not directly assessed.

The GP and MP samples exhibited the highest values for TEC and TPC (LSD test), i.e., in the heartwood samples taken from the ground and middle level of each post (Table 3). Slightly lower amounts of TEC were measured in the heartwood taken from the top of the posts (LSD test). This could be explained by the above-mentioned higher leaching of extractives from the wood that was more exposed to weathering (Table 3). Still, the lower TEC value in the TP samples did not affect the reduction of decay resistance (Table 2). The sound resistance of the TP samples to decay with test fungi (Table 2) could be explained by the high proportion of polyphenols in the acetone-soluble extract of the TP samples (Table 2). Since phenolic compounds are often the key to antioxidant, biocidal, anti-inflammatory and fungicidal activity [48,49], the higher the proportion of polyphenols in the hydrophilic crude wood extract, the more the extract could exhibit these desired properties. No significant differences were found when comparing the TPC/TEC values between the samples tested (ANOVA, $p = 0.679$, LSD test). However, the highest values were measured in the TP samples (Table 3).

High extractive content is consistent with high inherent durability. Namely, the exposure of black locust wood to brown rot fungus *G. trabeum* results in insignificant decay. Although the decay on the posts in use has signs of brown rot decay, *G. trabeum* could not decay black locust wood (Table 2). Thus, it is very likely that the brown rot decay noticed on posts was a consequence of some other fungi and/or soft rot decay [50], which causes degradation of wood in ground contact. In addition, it should be considered that brown rot fungi are more prevalent in conifers, while some species have proved their ability to degrade hardwoods [38]. White rot fungi *T. versicolor* caused slightly greater mass loss in the specimens' middle sections (5.1 %) and *H. fragiforme* on the reference black locust from the reference (freshly cut) cut post (6.2 %). In line with the durability standard EN 350 [15], black locust wood is categorised as durability class 1 (lower and upper part of old posts) and durability class 2 (middle part of the old posts and recent posts) (Table 2). The durability of the weathered wood might be different; however, the weathered layer was only one ring wide, and thus, it was not possible to prepare comparable specimens out of the weathered layer.

Besides inherent durability, the service life of the wood is characterised by its water performance [51]. Generally, those wood species that take up less water during hydrological events and dry out faster will have a longer service life. The water performance of old and recent black locust posts seems comparable. Recently harvested black locust wood absorbs slightly more water vapour during conditioning in a saturated atmosphere and absorbs slightly more liquid water when immersed. The differences can likely be attributed to varying wood densities. As the weathered layer was not tested, the influence of weathering on moisture performance was less prominent, as reported in some other studies where weathered surfaces were part of the tested specimens [52].

Wood-water interaction depends on several factors, such as the presence of tyloses in its anatomical structure, pit aspiration, permeability, and other anatomical properties [53]. Table 4 shows that old black locust has better moisture performance ($k_{wa} = 2.0$) than recent wood ($k_{wa} = 1.5$). Overall, the moisture performance of black locust is considerably superior to that of beech wood ($k_{wa} = 0.9$), predominantly due to tyloses that limit liquid water penetration to wood [11]. The indicators are calculated from the median values of individual measurements; thus, we cannot provide deviation measures.

Besides moisture performance, the k_{inh} factor, indicating resistance to microbiological degradation, is significant in wood's outdoor performance. The durability of wooden products in external conditions, be it in soil contact or above-ground, is primarily due to their content of biologically active extractives or due to chemical treatments (biocides). Similar to the k_{wa} factor, the k_{inh} factor is subject to a limitation of 5. The k_{inh} of black locust heartwood varies between 4.5 (lower part of the posts) and 5.0 (newly harvested posts). In the past studies, the material performance was determined for other wood species as well, and comparison of respective data with literature ones indicates improvement over European oak (3.9) and comparable to the inherent durability of sweet chestnut (5.0) [54].

According to Meyer-Veltrup [12], the material resistance dose (d_{Rd}) was determined using a critical dose of 325 days, irrespective of the wood species. This represents the days with conditions suitable for fungal decay before deterioration begins. The resistance dose of reference black locust (2517 days) was higher than that of the English oak (1923) and sweet chestnut (2080). The heartwood of 40-year-old black locust posts from a restored vineyard showed higher resistance against wood degradation compared to reference (recently felled) black locust posts. The critical dose of the old posts varied between 2938 days (lower part of old posts) and 3237 days (middle part of old posts) (Table 4). This proves the high durability of the old black locust posts. Despite 40 years of weathering, their performance remained unchanged. Respective values indicate that the old posts can be reused, even in outdoor applications.

4. Conclusions

Durable wood species such as black locust are essential in agriculture, particularly for vineyard and orchard infrastructure, where a long service life is required. In a respective study 40-year-old black locust posts were compared with recent ones. The results proved that the old wood had better mechanical properties and durability. The old posts showed minimal decay despite 40 years of exposure, confirming the high natural durability of black locust heartwood. Factors like wettability and inherent durability were calculated, showing that the old black locust wood has improved material performance against fungal decay compared to recent wood and compared favourably to other durable wood species like oak and sweet chestnut.

CRediT authorship contribution statement

Boštjan Lesar: Writing – review & editing, Supervision, Formal analysis, Data curation. **Jernej Malik:** Investigation, Formal analysis, Data curation. **Jaka Levanič:** Writing – review & editing, Methodology, Investigation. **Miha Humar:** Writing – original draft, Visualization, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **Viljem Vek:** Writing – review & editing, Visualization, Validation, Investigation, Formal analysis, Data curation. **Eli Keržič:** Writing – review & editing, Formal analysis, Data curation.

Table 4

Average factors determining wood service life, calculated as per Meyer-Veltrup et al.'s methodology (2017) and information from Table 1.

Indicator	Black locust				Spruce	Beech
	Low	Middle	Upper	Reference*		
k_{inh}	4.5	4.9	4.8	5.0	1.0	0.5
k_{wa}	2.0	2.0	2.1	1.5	1.0	0.9
d_{Rd}	2938	3237	3228	2517	325	131
Rel. d_{Rd}	9.0	10.0	9.9	7.7	1.0	0.4

* Heartwood sample from a freshly felled black locust tree (for further information, see description in Materials and Methods).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Availability

Data will be made available on request.

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