Bio-based Methods with Potentials for Application in Wooden Furniture Industry

Biološke metode s potencijalom za primjenu u proizvodnji namještaja od drva

ABSTRACT • Furniture market is shifting towards green and innovative products. The use of bio-based methods in wooden furniture industry presents a big potential for the development of materials with new characteristics, of unique furniture items, and can reduce the environmental impact. Bio-based methods can be used for wood protection and decoration, fibre board production, and development of new wooden materials, such as wood hybrids and functionalised wood. The bio-based methods, investigated for their potentials in wood industry, include the use of living organisms, natural products, and biomimicry. Despite ongoing developments there are still major drawbacks associated with many of these technologies: unreliability and inadequate efficiency of the methods, inadequate mechanical properties or dimensional stability of the final products, and high costs. Thus, further developments are needed. In this review, we present the existing and arising bio-based methods with potential in wooden furniture production. Furthermore, we shortly present their marketing potential.

Key words: biotechnology; natural products; wood; furniture; wood protection; wood colouring; natural adhesives; wood functionalisation; biomimicry

SAŽETAK • Tržište namještaja sve se više pomiče prema zelenim i inovativnim proizvodima. Primjena bioloških metoda u proizvodnji namještaja od drva znači velik potencijal za razvoj materijala novih svojstava te za proizvodnju jedinstvenih predmeta namještaja. Osim toga, uvođenje bioloških metoda u industriju namještaja može pridonijeti i smanjenju štetnog utjecaja na okoliš. Biološke metode mogu primijeniti u zaštiti i dekoraciji drva, u proizvodnji ploča vlaknatica i u razvoju novih drvnih materijala kao što su drvni hibridi i funkcionalizirano drvo. Spomenute metode, čiji se potencijal primije u proizvodnji namještaja istražuje, uključuju biotehnologiju, uporabu prirodnih proizvoda i biomimikriju. Unatoč stalnom razvoju, još postoje znatni nedostatci povezani s primjenom tih tehnologija. To su složenost ili nepouzdanost metoda, neadekvatna mehanička svojstva ili dimenzijalna stabilitet konacnih proizvoda te visoki proizvodni troškovi. Stoga je potrebno i dalje razvijati te metode radi njihove primjene u proizvodnji namještaja. U ovom su radu predstavljene razvijene biološke metode i one koje su u fazi razvoja a imaju potencijal za primjenu u proizvodnji namještaja od drva. Usto je ukratko opisan i njihov marketing potencijal.

Ključne riječi: biotehnologija; prirodni proizvodi; drvo; namještaj; zaštita drva; bojenje drva; prirodna ljepila; funkcionalizacija drva; biomimikrija

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1 INTRODUCTION

1. UVOD

Furniture production represents a big market (International Wooden Furniture Markets: A review, 2004; Wang et al., 2016), which requires design of original products to move up the value chain. This, among others, includes upgrades of the manufacturing processes and of the final product (International..., 2004). Such original products can be designed with the use of innovative bio-based technologies.

Wood biotechnology and the use of natural products in wooden furniture industry have long history and are still being developed. They have potential for development of materials with new characteristics, unique furniture items, and can help to reduce the environmental impact (Burgert et al., 2015; Mai et al., 2004; Robinson et al., 2012). Applications based on organisms and their products with potential in wood industry can be classified into three categories: 1) biotechnological use of live organisms or their enzymes for production of new substance or for catalytic purposes (Mai et al., 2004; Smith, 2009), 2) use of extracts or other non-catalytic products of organisms (Yang, 2009), and 3) biomimicry (Chen et al., 2017; Umorina, 2017).

There are quite a few reviews describing specialised topics of wood biotechnology or the use of natural products in the wood industry. For example, wood protection and fibre board production has been previously described in Mai et al. (2004) and surface functionalisation in Petrić et al. (2013). Furthermore, advanced breeding methods for creation of new tree and wood varieties are gaining importance (Bhalerao et al., 2003). However, the latter is out of the scope of this review as we focus on the processing of wood for production of furniture. Moreover, we failed to find a general overview of methods based on live organisms or their products used in wood processing. Thus, we review developed and arising methods based on live organisms or their products with potential in wooden furniture industry. Our main focus is on the methods that have not yet been widely applied in the industry. We also briefly discuss the marketing potential of these technologies.

2 ADHESIVES AND WOODEN BOARDS

2. LJEPILA I DRVNE PLOČE

Normally, production of board materials requires the use of high pressure and temperatures as well as toxic chemicals. This is associated with higher costs and adverse environmental effects (Liu et al., 2010; Mai et al., 2004). Thus, more environmentally-friendly techniques are being developed, as described by Ferdosian et al. (2017). This includes both natural adhesives, such as lignin and plant proteins (Ferdosian et al., 2017), and the use of oxidative enzymes or live organisms to increase adhesive properties of wood and catalyse covalent bond formation between adhesives (Mai et al., 2004). Enzymatic systems can be single-component, utilising only oxidative enzymes such as peroxidases or laccases, which are most commonly used enzyme, or two-component with addition of lignin and similar phenolic substances as adhesives. (Mai et al., 2004; Widsten and Kandellbauer, 2008).

Enzymes can be used in pre-treatment of wooden fibres or to aid in the gluing processes. This can reduce the heat and glue content needed to produce medium-density fibre boards. The use of enzymes may also contribute to the mechanical properties of the boards (Fackler et al., 2008; Mai et al., 2004). Pre-treatment of fibre particles with laccases increases the self-bonding properties of the fibres surface (Gabrić and Pohleven, 2014). Furthermore, adhesive surface properties can be improved by enzymatic functionalisation. Lac-case-catalysed covalent binding of urea to fibres was shown to increase the adhesion. However, this effects was smaller than the effects of board density and glue content (Fackler et al., 2008). Laccase was also tested at the pilot level for catalysis of bonds between lignin molecules already present in the fibre particles. The process is claimed to have a potential, but it is limited by poor dimensional stability of the product and the need for the use of higher temperatures in the processing of boards (Felby et al., 2002). Cost effective production of laccases is also being studied. Laccase producing fungi can be grown on medium where main nutrients are waste materials (Zhou et al., 2014).

The use of lignin as an adhesive has been thoroughly investigated. Lignin can be used to partially substitute phenolic components in synthetic adhesives. Products created with such an adhesive have only slightly reduced strength retention and only slightly higher water uptake (Jin et al., 1990). Lignin can be produced either with wood degradation by brown rot fungi, which is a time consuming process with difficult extraction steps and requires further enzymatic processing of lignin, or from the industrial waste, which contains lignin with reduced adhesive properties (Gabrić and Pohleven, 2014; Jin et al., 1990; Mai et al., 2004). An alternative to lignin adhesives is the use of proteins. A combination of soy proteins and CaCO₃ resulted in a glue with good adhesive properties and water resistance (Liu et al., 2010).

3 WOOD PROTECTION

3. ZAŠTITA DRVYA

Wood must be protected against biological and abiotic factors in all stages of furniture production (Yang, 2009). Selection of preservatives depends on the intended use of the wooden material, e.g. indoor or outdoor. Some outdoor protectants can be harmful to human health, leading to respiratory problems and allergies or even serious medical complications. They can also have negative effects on environment, especially at the time of the disposal (Pánek et al., 2014). Examples of traditional preservatives with negative effects on the health are those containing compounds of arsenic, zinc, copper, and creosotic oil. Due to their adverse effects they are often prohibited from the use in furniture industry (Pánek et al., 2014; Schubert et al., 2012). Therefore, new wood protection techno-
gies are being developed. Biological protectants can have more targeted mode of action against wood pathogens and are biodegradable. However, they are also more sensitive to degradation and hence require special care (Mai et al., 2004). Another option for protection against pathogens is modification of wood properties, leading to more hydrophobic nature and reduced water content of wood (Burgert et al., 2015; Humar and Lesar, 2013).

3.1 Protection with microorganisms

3.1.1 Zaštita mikroorganizmima

Pathogenic organisms cause wood degradation and loss of mechanical properties, unwanted colouring, and production of harmful toxins (Yang, 2009). Due to high humidity in some living spaces, it is necessary to protect wood against pathogenic microorganisms. This can be done with the inoculation of wood with protective non-pathogenic organisms (Bruce & King, 1991; Mai et al., 2004), as further described by Mai et al. (2004) and Susi et al. (2011). Bio-controlling organisms compete with the pathogens or produce compounds that prevent the growth of pathogens (Mai et al., 2004; Susi et al., 2011). However, protection with microorganisms is not long-lasting, retaining effectiveness only for a few years (Bruce & King, 1991; Mai et al., 2004). It also has varying results against different fungi and in different environments (Mai et al., 2004). Microbial extracts may improve the reliability of protection under varying conditions (Yang, 2009). However, bio-control fungi only provide preventive protection against the invasive fungi. Thus, it is important to apply the protective organism already during the production of furniture (Bruce & King, 1991; Mai et al., 2004). On the other hand, application of bacterial and fungal spores on wood already infected by insects has some potential (Mai et al., 2004). Bio-finishes based on black mould and oil are already used in practice (van Nieuwenhuijzen et al., 2016). On the other hand, some bio-controlling organisms will require further research before becoming commercially applicable. These include Streptomyces isolates (Jung et al., 2018) and Bacillus subtilis that can be combined with the application of essential oils (Sajitha et al., 2018; Wang et al., 2012).

Fungi can also be used for increasing the permeability of the outdoors wood to commercial preservatives. However, the technology is still not regarded as economically feasible (Schwarze & Schubert, 2017; Thaler et al., 2012).

3.2 Protection with natural products

3.2.1 Zaštita prirodnim proizvodima

Natural protectants have a long tradition. Many protectants like resins, extractives, essential oils, and lignin are still being further tested (Fernández-Costas et al., 2017) and some have also been patented (Yang, 2009). Examples include capsaiacin containing extract from chilli, extracts from durable wood species containing tannins, flavonoids, and terpenoids, and essential oils containing phenols (Pánek et al., 2014). The application of different extracts for the protection of wood is more thoroughly described in Yang (2009).

The use of natural protectants has various benefits. They can be applied as a protection against organisms from different kingdoms, can be nontoxic to humans, and are produced from renewable sources – organisms, ranging from plants to fungi and bacteria (Pánek et al., 2014; Yang, 2009). Treatment with natural products can change the surface properties of wood and thus reduce the leaching of other protectants (Fernández-Costas et al., 2017). Multifunctional protectants that also serve as dyes have been investigated (Colak, 2016; Ozen et al., 2014). Furthermore, protectants can be extracted from waste materials. An example is bark, which has protective potential due to high content of tannins, resins, and waxes (Yang, 2009). Similarly, lignin, a waste product from paper industry, has potential as protectant due to its phenolic content (Fernández-Costas et al., 2017). Some plant extracts with antifungal properties, such as mimosa and quebracho extracts, are already commercially available (Tascioglu et al., 2013).

However, the use of natural protectants still poses a problem. Their activity can be inconsistent and some of them are subjected to microbial or UV degradation, being suitable only for interior use (Pánek et al., 2014). Furthermore, they can be subjected to leaching or are insoluble in water, thus requiring the use of organic solvents (Yang, 2009).

3.3 Enzymatic ligation of protectants

3.3.1 Enzimsko povezivanje zaštitnih sredstava

Preservatives are often subjected to leaching from wood. This can be prevented by chemical ligation or grafting of preservatives into the wood. Enzymes can catalyse the creation of covalent bonds between wood and preservative (Kudanga et al., 2008; Petrić, 2013; Schubert et al., 2012). In comparison to chemical and physical methods of functionalisation, the use of enzymes is more environmentally friendly due to the reduced use of energy and chemicals (Kudanga et al., 2008). Additionally, the use of enzymes removes the need for expensive catalysts (Slagman et al., 2018). However, poor penetration of the enzymes into the wood poses a problem for the use of enzymatic grafting (Slagman et al., 2018).

Oxidases, including laccases, are used for grafting. Laccases, in contrast to other oxidases, require only oxygen and not hydrogen peroxide for oxidation. Furthermore, the addition of mediators enables oxidation of substances that otherwise do not fit in the active site of laccases (Slagman et al., 2018). Grafting often involves the use of phenolic compounds, although other substrates have been tested as well (Slagman et al., 2018). One of such examples is the use of iodine, which is cheap and is not associated with microbial resistance. Oxidation of iodide (I⁻), which has no antimicrobial activity, to antimicrobial three iodide (I₃⁻) with laccases and mediators leads to binding of three iodide to aromatic groups of lignin. This provides protection against bacteria, yeast and higher fungi. The use of laccases prevented leaching of the protectant and led to similar effectiveness as a commercial preservative. Furthermore, the lignin degradation by laccases was reported to be
small (Schubert et al., 2012). Additional improvements can be achieved by the use of anchoring molecules that are covalently bound to the wood and serve as anchors for protectant binding (Kudanga et al., 2008).

3.4 Surface treatments for increased hydrophobicity

Wood absorbs water both from vapour and liquid state (Glass and Zelinka, 2010). This can lead to swelling and cracking of wood and enables colonisation by pathogens (Burgert et al., 2015; Mai et al., 2004). Cell wall moisture content and hence biological degradation of indoor wood is dependent on the environmental humidity, temperature and ventilation (Mai et al., 2004; Žlahtić and Humar, 2016). Wood with moisture content below 12 % is usually not affected by biological degradation, moisture level of 12-18 % enables infestation by insect, above 18 % enables mould growth, 28-33 % enables growth of higher fungi, and if moisture increases even further, the wood can be affected by bacterial degradation (Mai et al., 2004). Fungal colonisation depends on average moisture over time. Thus applied protectants must prevent both water absorption and allow drying of wood after the exposure to water (Humar and Lesar, 2013).

Many different approaches for reducing the water content of wood have been tested. Lumen of the cells in the wood can be filled up or the surface characteristics of the wood and cell walls may be changed, for example with alklylation of hydrophilic functional groups of lignin, cellulose and hemicellulose (Burgert et al., 2015). Water repellents, such as waxes and oils, including linseed and tung oils, are especially useful as they provide protection against water absorption and at the same time do not seal the wood surface, enabling wood drying (Humar & Lesar, 2013). Combinations of both oils and waxes were also shown to be beneficial (Žlahtić and Humar, 2016). Effectiveness of repellents depends on the successful impregnation of wood. This is affected by wood permeability and characteristics of the repellent. Performance of repellents thus varies across wood species (Humar and Lesar, 2013). Traditional agents used for decreased water absorption, such as waxes, resins and oils, are subjected to leaching from wood. Thus, it was proposed that laccases should be used for binding of hydrophobic molecules, such as lauryl gallate, on the surface of wood and subsequent creation of a resistant hydrophobic layer (Fernández-Fernández et al., 2015).

Another option is bio-mimicry of super-hydrophobic surfaces that repel water and also have self-cleaning properties. Super hydrophobic surfaces can be created by surface wrinkling, electrospinning, template-based extrusion, photolithography and soft lithography (Chen et al., 2017). General information about these methods is available elsewhere (Bhardwaj & Kundu, 2010; Meng et al., 2016; Ouyang et al., 2015; Qin et al., 2010; Raoufi et al., 2015). For example, a super-hydrophobic surface pattern imitation of Colocasia esculenta leaf was produced on the wood with soft lithography (Chen et al., 2017).

4 DECORATION

4.1 Natural dyes

Consumers are becoming interested in natural dyes as production of synthetic dyes is often environmentally unfriendly and their use can be potentially harmful to health (Colak, 2016; Prabhu & Bhute, 2012; Yeniocak et al., 2015). Different natural dyes are still being tested, such as extracts from pomegranate, red beetroot, and fungi (Colak, 2016; Vega Gutierrez et al., 2016; Yeniocak et al., 2015).

However, there are also downsides of using natural dyes. The final colour can depend on wood composition and may be affected by UV (Yeniocak et al., 2015). Some dyes do not penetrate into the wood and thus colour only the surface (Vega Gutierrez et al., 2016). Furthermore, natural dyes can have poor affinity for binding to the wooden surfaces. Their resistance to discoloration can be improved by the use of mordants, which form complexes with dyes and thus increase their binding to the surface. Metal-based mordants (e.g. iron, aluminium) and vinegar are among commonly tested mordants for colouring of the wood and other natural products. (Colak, 2016; Goktas et al., 2008; Prabhu & Bhute, 2012; Vega Gutierrez et al., 2016; Yeniocak et al., 2017). However, mordants can lead to colour changes of the dye. Furthermore, some of the mordants, including the metal-based ones, have toxic properties (Prabhu & Bhute, 2012). Therefore, further research is needed to produce resistant natural dyes.

4.2 Spalting

Colouring of wood can also be achieved by the use of live organisms, which produce unique patterns and can excrete protective antimicrobial substances. Process of wood colouration based on dye secretion by organisms inhabiting the wood is called spalting. As many consumers desire unique wooden products, spalted wood is highly valued, regardless of the wood species used (Robinson et al., 2012). One of the main concerns is the loss of mechanical properties after spalting. Thus, the use of dense hardwood has been advised (Robinson et al., 2007; Robinson et al., 2012). However, spalted wood does not have importantly reduced mechanical or acoustic properties. Moreover, spalting increases wood permeability, affecting gluing and surface finishing of the products (Robinson et al., 2013b). Increased permeability can be beneficial, leading to better impregnation (Schubert et al., 2011).

Spalting can result in various patterns and shades, depending on the used microorganism. Zone lines are usually produced by white rot fungi, while ascomycetes produce wood colouring (Robinson et al., 2011a). Spalt-
ing can be a consequence of excreted dyes with low molecular mass or inoculation of wood with fungi that have pigmented cell walls, leading to zone lines and blue-grey colouring, also known as blue stain (Robinson et al., 2012). Zone lines are easy to produce and can be created by the use of various fungi (Robinson et al., 2011b). Zone lines are often produced as the result of competition, for example between Trametes versicolor and Bjerkandera adusta or Inonotus hispidus and Xylaria polymorpha. Xylaria polymorpha can produce zone lines even when individually inoculated and without application of stressful conditions (Robinson, 2012; Robinson et al., 2012). Blue stain of sapwood is produced by fungi from Ophiostoma genera that are in nature transmitted by bark beetles. However, blue stain wood is less popular among consumers (Robinson et al., 2013b). Pink stain is produced by naphthoquinone of Arthrographeis cuboidea and xylindein of Scytalidium cuboideum, also on conifers and bamboo. However, Scytalidium cuboideum produces zone lines instead of pink pigmentation when grown together with other fungi. Bright blue-green pigmentation arises due to xylindein produced by Chlorociboria genus on poplar wood. Yellow stain is produced by quinones of Scytalidium ganodermophthorum (Ma et al., 2004; Robinson, 2012; Robinson et al., 2013a; Robinson et al., 2013b; Vega Gutierrez et al., 2016). Furthermore, wood can be inoculated with a mixture of fungi or inoculated more than once with different fungi (Robinson et al., 2013b). For example, increased visibility of spalting can be achieved by initial bleaching of wood with white rot fungi, sterilisation and subsequent inoculation with the desired spalting fungi. However, sterilisation can only be used for small wood pieces, as increased volume leads to overly prolonged sterilisation times (Robinson et al., 2012). Nevertheless, this method can still be used for production of “furniture jewellery”.

Spalting can be adopted at the industrial level (Robinson et al., 2011a). It was tested by Robinson et al. (2013a), who discovered that specific combinations of Scytalidium cuboideum, Xylaria polymorpha and Trametes versicolor produce the best zone lines. In order to achieve spalting fungi must be able to penetrate into the wood and grow inside it (Robinson et al., 2012; Vega Gutierrez et al., 2016). At the industrial level it is important to choose the right inoculation method, depending on the fungi (Robinson et al., 2013a). Additionally, prior sterilisation can increase the pigmentation (Robinson et al., 2011b). Growth of the fungi is then stopped before the loss of mechanical properties of wood (Robinson et al., 2011a). Fungal growth and spalting depend on many parameters (Robinson et al., 2011a), including wood species, which must be chosen based on the desired pigmentation. For example, sugar maple can be spalted by a broad range of fungi, while some wood species can be spalted with only certain fungi or none at all (Robinson et al., 2011a). Antifungal substances in wood can importantly reduce fungal growth, while some stressors may increase the spalting. Sugar content also affects the spalting (Robinson et al., 2011a). However, the success of spalting varies greatly and thus reliable combinations of wood and fungi should be chosen (Robinson, 2012).

5 NEW WOODEN MATERIALS

5.1 Wood densification

Density is one of the main factors affecting mechanical properties of wood. Wood densification can increase homogeneity and mechanical properties, while retaining the ordered structure of wood. (Frey et al., 2018). It increases hardness and surface abrasion resistance and can lead to colour changes (Cruz et al., 2018; Sozbir and Bektas, 2017). Densification can be used to improve mechanical properties of wood of low-density species. Therefore, hardwood species can be replaced by low-density species in applications such as table tops and floors (Sozbir and Bektas, 2017). Process of wood surface densification has been already industrialised (Sandberg et al., 2017). On the other hand, lightweight wooden materials reduce economic and ecological burden of furniture transport (Iejavs and Spulle, 2016) and have potential for multifunctional furniture.

Wood densification process is comprised of wood softening by moistening and heat treatment, followed by compression leading to collapse of cell walls, and is finished by locking the wood in compressed state by drying and cooling. Fixation of the compressed state can be further improved by impregnation with adhesives (Sandberg et al., 2017; Sozbir & Bektas, 2017). The process is usually applied only to the surface of the wood, leading to greater usage efficiency of the material, easier production and better mechanical properties for certain applications (Sandberg et al., 2017). Uneven compression enables production of wood with gradual variation in density and stiffness (Frey et al., 2018). Furthermore, chemical composition of wood importantly affects the mechanical properties of densified wood, as was shows on Pinus radiata (Cruz et al., 2018). Delignification can be used to ease the curving or twisting of wood (Frey et al., 2018).

5.2 Wood functionalisation and hybrid materials

Wood can be functionalised to induce changes in its property profile. For example, incorporation of mineral particles into the wood can increase strength, fracture resistance, hardness, and stiffness (Burgert et al., 2015). Furthermore, changes in magnetic, conductor and optical properties could be used to extend the range of applications of wood into electrotechnical industry (Burgert et al., 2015; Gan et al., 2017; Li et al., 2018). Transparent wood has already been produced; howev-
er, its optical properties are still greatly dependent on thickness and any subsequent compression of the material. It has potential for the use in buildings due to its low density and light transmittance as well as reduced heat conductivity and frailness in comparison to glass (Li et al., 2018). Furthermore, transparent wood can be functionalised with luminescent properties (Gan et al., 2017; Li et al., 2018).

Transparent wood can be manufactured by delignification or removal of chromophores followed by impregnation with polymer with refractive index matching the wood. The polymer fills pores in the wood that would otherwise lead to scattering of the light (Gan et al., 2017; Li et al., 2018). However, delignification is time consuming and can pose a burden for the environment (Li et al., 2018). Furthermore, functionalisation of bulk wood is challenging. This could potentially be improved by separation of wood into fibres, which would be functionalised and then re-aligned into the wooden structure (Frey et al., 2018). For example, Gradwell et al. (2004) used soluble pullulan as a model for lignin. Pullulan adsorbed to the cellulose surface leads to self-assembly (Gradwell et al., 2004).

Wood can also be used to produce hybrids with synthetic or inorganic materials. The main benefit of wood incorporation is its ordered structure (Burgert et al., 2015; Croitoru et al., 2018). For example, wood can serve as a framework for production of synthetic materials in which it is otherwise challenging to produce an ordered structure. This has potential for optical implications (Burgert et al., 2015). Furthermore, it was proposed that wood may be useful for substituting synthetic polymers (Li et al., 2018). Wooden fibres incorporated into plastics are already being used in the industry. However, protectants used in such materials often pose health risks (Croitoru et al., 2018). Thus, ionic liquids, substances composed entirely from ions with melting point below 100 °C (Lei et al., 2017), were proposed as a substitute (Croitoru et al., 2018).

6 MARKETING POTENTIAL
6. MARKETIŃSKI POTENCJAL

Innovations in the wood industry promise better visual and mechanical properties as well as reduced burden for the environment. This has potential for marketing, as consumers already associate wood with wellbeing, aesthetics and environmental friendliness (Manuel et al., 2015). Uniqueness is highly valued among consumers, especially when purchasing items with hedonistic rather than strictly functional role (Reich et al., 2017). Thus, “furniture jewellery” applications may have a good potential. Furthermore, the lifespan of furniture design is shortening (Scholz and Decker, 2007) and thus novel wood processing technologies may bring about innovations desired by consumers.

Environmental friendliness is important decision factor for many consumers, as shown by a Brazilian study, in which consumers were prepared to pay more for environmentally friendly furniture (de Medeiros et al., 2016). Environmental friendliness can be achieved by the reduced use of energy and resources, recycling and waste reduction, and by following the principles of sustainable development (Huang et al., 2012). However, main attributes in the choice of furniture are still elsewhere, including: comfort, design, (de Medeiros et al., 2016; Holopainen et al., 2014), brand, price (Caia et al., 2017), and durability (Holopainen et al., 2014).

Marketing for new technologies can be challenging. The degree of newness in a product must be balanced, as consumers can distrust the usability of the product or are disheartened by their own uncertainty about the proper maintenance of the item (Cojocaru et al., 2013). Additionally, it has been shown in a Chinese study that eco-labels are often distrusted and that many consumers are unable to distinguish between ordinary and green furniture (Caia et al., 2017). Thus, not only the development of new technologies, but also research in their marketing must be conducted.

7 CONCLUSION
7. ZAKLJUČAK

The use of biotechnology, natural products or nature-inspired methods has great potential in furniture industry. These methods can lead to production of eco-friendly wood with changed physical properties and unique visual characteristics. Here presented methods may thus inspire the development of new wooden furniture products.

In general, most investigated methods include the use of enzymes, live organisms, and natural products. Additionally, production of functionalised wood and hybrid materials is also gaining importance. Nevertheless, many applications are still not developed at the industrial level. Common drawbacks include complexity or unreliability of the methods, inadequate mechanical properties or dimensional stability of the final products, and high costs. Thus, further research on both laboratory and pilot scale is required.

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