EFFECT OF STEAMING ON THE COLOUR CHANGE OF SOFTWOODS

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The heat treatment of softwood (*i.e.* spruce, pine, fir, and larch) may result in significant colour changes. During this study Scots pine and spruce samples were steamed and analysed for their altered hue and lightness. Treatments included: 0 to 22 days of steaming time at a temperature range of 70 to 100°C. The outcome included a variety of colours between the initial hues and brownish tint. These new colours are similar to that of aged furniture and indoor wooden structures. Consequently, properly steamed softwood may be used to repair historical artefacts and relic furniture. Besides restoration, steamed stocks are excellent sources for manufacture of periodical furniture, where the aged appearance has aesthetical value. Results however, indicated that steaming at a temperature above 90 ˚C has a bleaching effect, *i.e.* the coloured chemical components formed by moderate steaming may be removed. Furthermore, we observed a linear correlation between lightness and colour hue at all steaming times and temperatures.

Keywords: Steaming; Colour modification; Scots pine; Spruce

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INTRODUCTION

The natural tint of wood varies between light yellow and dark brown, usually with a certain degree of colour inhomogeneity. The diversity is due to the different colours of the inside lumen surfaces, cell walls, and earlywood/latewood regions in any anatomical planes of the machined surfaces. Wood has one of the most beautiful colour harmonies created by nature, because its colour range and the colour pattern provide emotive comfort for the observer (Masuda 2001). However, not all of the wood species have attractive colour. There are a few species with white-greyish tint without any visible texture. Some of them may have inhomogeneous colour. Both disadvantages can be modified by steaming.

Industrial scale steam treatment of wood to achieve colour changes was started as early as the second half of the last century (Molnar 1976). Mostly beech and black locust timbers were steamed. Beech (*Fagus*) is usually steamed to turn its white-grey initial colour into a more attractive reddish colour. The sharp colour difference between white and red heartwood of beech can also be alleviated by steaming (Tolvaj *et al.* 2009). The systematic research to explore the specific effects of steaming parameters for individual wood species started about twenty years ago. Primarily the steaming behaviour and discolouration of black locust (*Robinia pseudoacacia* L.) were the targets of these investigations. Some relevant discussions were provided by Tolvaj and Faix (1996), Molnar (1998), Horvath (2000), Horvath and Varga (2000), and Tolvaj *et al.* (2010). During a research project, Horvath (2000) developed an exponential function that provided a good fit to the temperature and time dependency of lightness change for black locust exposed to steaming. On the other hand, there have been only a few publications regarding the steaming properties of other species than beech and black locust. Varga and van der Zee (2008) investigated some mechanical property changes under different steam treatment conditions. Their research involved two European and two tropical hardwood species. Colour variations of steamed cherry (*Prunus*) wood were discussed by Straze and Gorisek (2008) and by Dianiskova *et al.* (2008). Recently, the steaming properties of Turkey oak (*Quercus cerris* L.) were presented by Tolvaj and Molnar (2006) and by Todaro *et al.* (2012a,b). Although a significant percentage of indoor wooden objects are made of softwoods, the time-temperature dependent discolouration of gymnosperms is a neglected researched area.

The colour of solid wood is quite sensitive to light and heat. Along with the ageing, indoor wooden structures including flooring, furniture, and joinery products, undergo discolouration. Decades-old light-coloured wood surfaces have become more brownish and darker. Retrofitting artefacts may be difficult because of the unmatched colour of the old and new pieces. Sometimes chemicals are used to achieve the desired tint of ageing; however, this is literally a “superficial” solution. Surface damages and post-treatment machining may expose the fresh colour of the substituted parts. The colour of steamed wood is homogeneous throughout the whole cross section. Thus, heat-treated parts are practically equivalent in colour to that of naturally aged wood constituents.

Based on the above mentioned arguments, an extensive research project was conducted with the following objectives. The primary goal of this study was to explore the practicality of steaming to achieve colour modification of softwoods. The study included the identification of optimal steaming parameters to achieve a particular colour hue by measuring standard C.I.E. $L^*a^*b^*$ colour coordinates. Our intent was to develop graphical representations for the visualization of steaming time/temperature and colour parameter relations. Such diagrams may aid the selection of appropriate steaming parameters to bring about desired colour hues and darkness of softwoods.

EXPERIMENTAL

Two conifers, Scots pine (*Pinus sylvestris* L.) sapwood and spruce (*Picea abies* Mill.) were selected for analyses. These are the most frequently used softwood species in Hungry for furniture and indoor products manufacture. All species were represented by a series of 10 samples for each steaming temperature, and 10 points were measured on each sample. The sample dimensions were 100 x 30 x 10 mm. The radially cut in-plane (*i.e.* 100 x 30 mm) surfaces contained sapwood and heartwood regions as well. The initial moisture content of the samples was between 10 to 12%, and the machined surfaces underwent a slight sanding. The treatment was carried out in a steaming vat with a 100% relative humidity condition at pre-set temperatures of 70, 80, 90, 95, and 100°C. A heat sensor regulated the temperature automatically around the set values with a tolerance of

0.5°C. The schedule of treating time comprised of 1, 2, 4, 6, 9, 12, 15, 18, and 22 days of steaming. Specimens were removed right after the designated steaming time elapsed. Prior to and after treatments, the specimens were kept under normal laboratory conditions (*i.e*. 65 % RH and T = 21˚C) that followed by initial and post treatment colour assessments. Measurements were carried out with a colorimeter (Konica-Minolta 2600d). The L^*, a^*, b^* colour co-ordinates were calculated based on the D_{65} illuminant and 10° standard observer with a test-window diameter of 8 mm. The relatively large window was chosen to measure the average colour of earlywood and latewood regions combined. Measurements on untreated samples served as control values for comparison purposes.

RESULTS AND DISCUSSION

The specimens became visibly darker during steaming, and the colour hue turned towards brown. These changes were sensitive to the steaming temperature and to the steaming time. In chemical terms, the observed colour change can be attributed to the alteration of the conjugated double bond systems found mainly in extractives (Tolvaj *et al.* 2010; Nemeth 1997). Wood species having high extractive content (*e.g*. black locust) can undergo great colour changes by steaming. Conifers generally have moderate extractive content that is sufficient for colour modification by steaming. As demonstrated in Figs. 1 and 2, the lightness of spruce and Scots pine samples decreased in the whole time interval with the increase of treatment time. The increasing temperature resulted in rapid lightness decrease during the first 4 days of treatment for both species. However, at 70°C treatment temperature this trend could not be observed. Apparently this is because 70°C is not high enough to initiate substantial chemical changes.

The lightness decrease of the examined two conifers was similar. The only difference was that the lightness of Scots pine samples hardly altered beyond the 18th days of steaming. In contrast, spruce samples exhibited a continuous lightness decrease during the 22 days of treatment.

The red colour co-ordinates showed more distinct deviations between the examined species (Figs. 3 and 4) than lightness did. The 70°C temperature produced slow but continuous redness increase. Steaming at 80°C generated the same redness alteration for Scots pine as the 70°C treatment temperature did. However, spruce suffered much greater red colour change than that of Scots pine at 80°C. In fact, steaming at 80˚C temperature bestowed the highest a^* value for spruce after the 22 days of treatment. Up to 9 days of treatment, the higher temperatures caused a higher increase in redness for both species, except in the case of 100 ˚C treatment temperature. In that case the initial redness increase was slightly less intensive for spruce and considerably less for Scots pine compared to the a^* values detected at 90°C treatments. 100°C was the only temperature for which a redness decrease was observed after 12 days of treatment for spruce and after 6 days for Scots pine.

During steaming, new chemical components are formulated that contain conjugated double bond systems as a result of the extractives thermal degradation. In comparison, poplar (*Populus* spp.), which hardly has any extractives, changes its colour only by a limited value towards red by steaming (Tolvaj and Faix 1996).

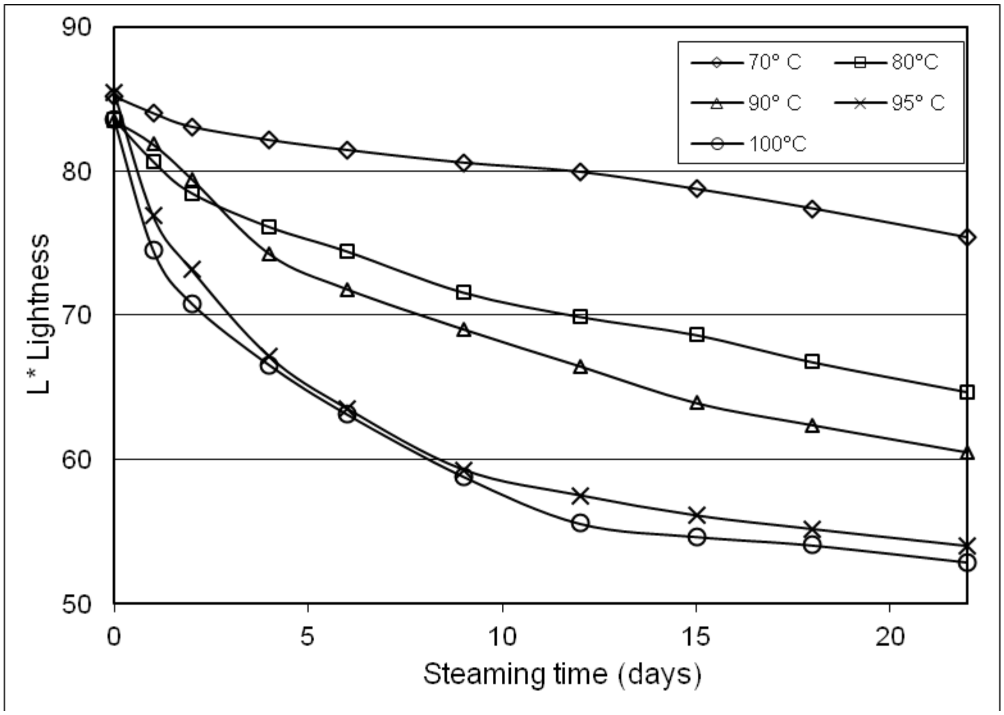

Fig. 1. The effect of steaming on the lightness (*L**) change of spruce (*Picea abies* Mill.)

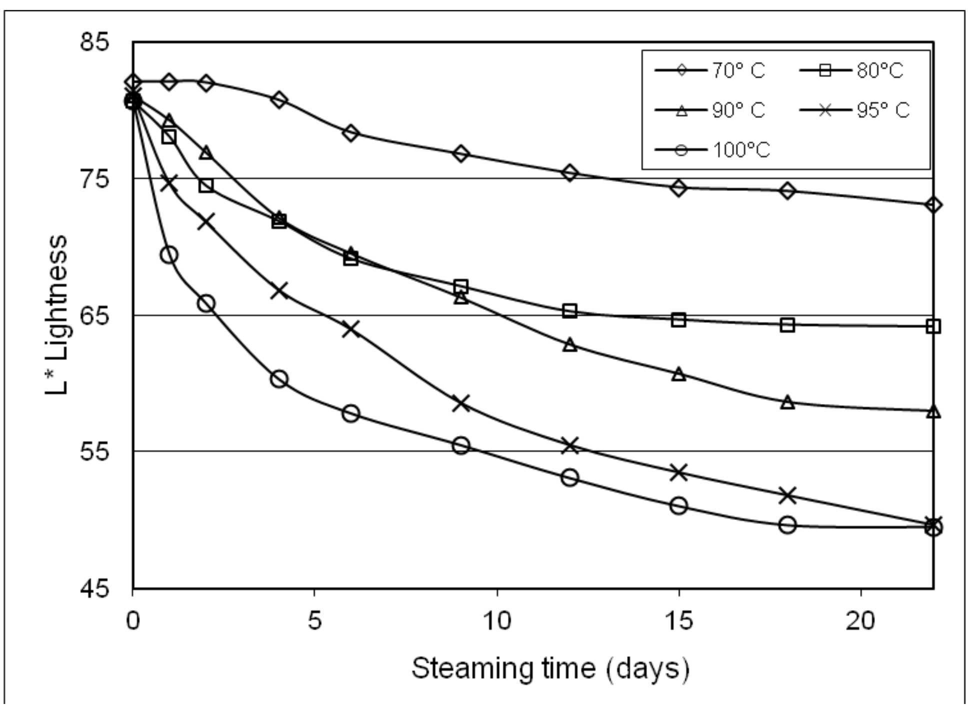

Fig. 2. The effect of steaming on the lightness change of Scots pine (*Pinus sylvestris* L.)

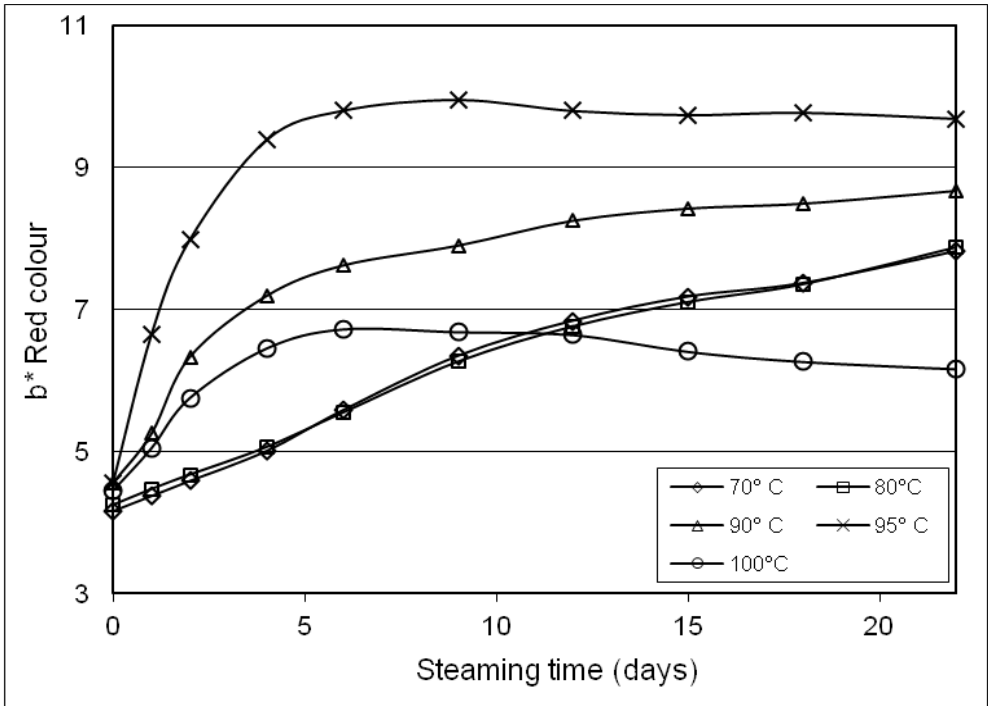

Fig. 3. Changes of red colour co-ordinates (*a**) of spruce (*Picea abies* Mill.) as a function of steaming parameters

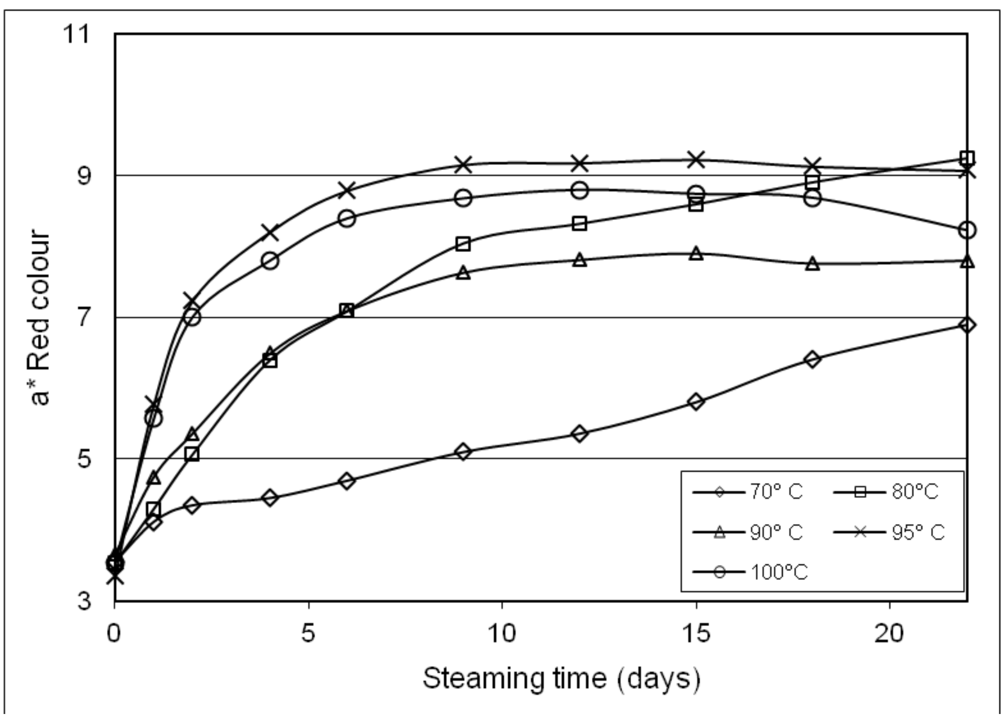

Fig. 4. Changes of red colour co-ordinates (*a**) of Scots pine (*Pinus sylvestris* L.) as a function of steaming parameters

These newly created, coloured molecules are extractable, and the hot steam leaches them out, decreasing the values of the a^* co-ordinates. These leached components can be found in the condensed water of the steaming. Similar results and observations were found and reported by Tolvaj *et al.* in 2010 when they steamed black locust specimens. The changes of yellow colour coordinate (b*) demonstrate the leaching effect more clearly (Figs. 5 and 6). Only the 70°C treatment temperature resulted in continuous increase of yellowness for both species.

For Scots pine specimens, the 80°C temperature resulted in a lower yellow colour increase than the 70°C treatment did. Most of the other trend lines for spruce had distinct maximum values that were observed after 15, 6, 4, and 2 days of treatments for 80°C, 90°C, 95°C, and 100°C temperature, respectively (Fig. 5). The temperature had a shifting effect on the location of the maximum values of redness, *i.e*. higher temperature causes an earlier decrease in b^* values. It does appear that the steam leached out almost all of chromophoric groups which were created during steaming at 100°C.

The yellowness change of Scots pine exhibited somewhat different behaviour than spruce (Fig. 6). The initial yellowness of Scots pine was definitely higher than the base b^* values of spruce. Similarly to that of spruce, the lower temperature treatments (70 and 80˚C) steadily increase the value of b^*. However, no distinct peak values were identified, except following 95˚C treatment, after 4 days of exposure.

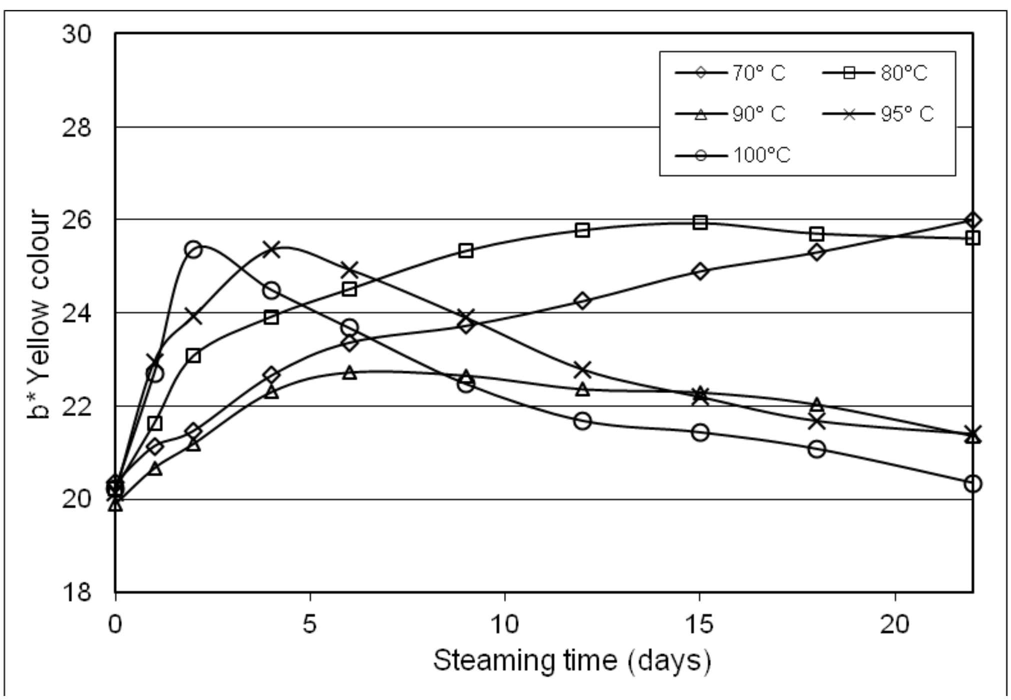

Fig. 5. The effect of steaming on the yellow colour co-ordinates (*b**) for spruce (*Picea abies* Mill.)

Previous studies demonstrated a linear correlation between lightness and colour hue of steamed black locust solid wood specimens (Tolvaj and Nemeth 2008). Furthermore, Tolvaj and Mitsui (2010) reported similar correlations when studying the discoloration effects of photodegradation.

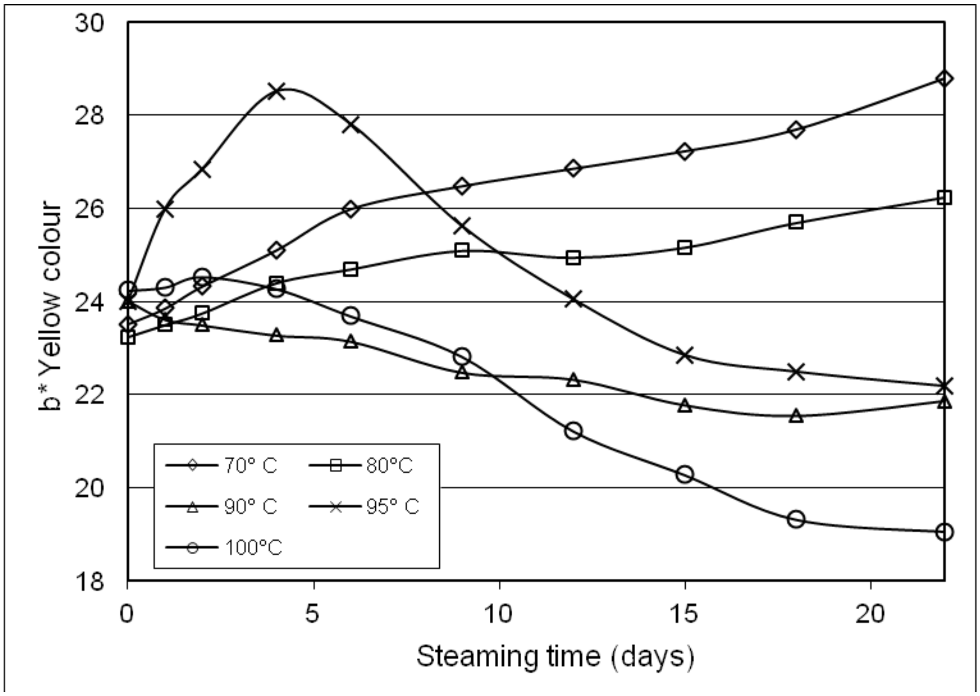

Fig. 6. The effect of steaming on the yellow colour co-ordinates (*b**) of Scots pine (*Pinus sylvestris* L.)

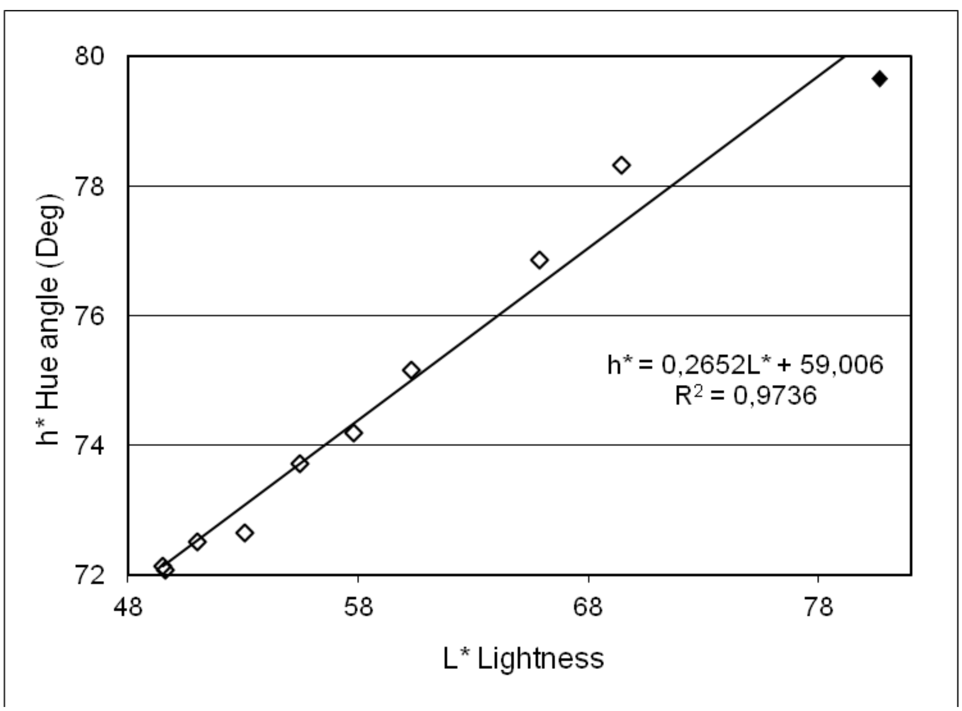

Fig. 7. Correlation between lightness (*L**) and hue angle (*h**) of Scots pine (*Pinus sylvestris* L.), steamed at 100°C

During the course of this research, we investigated this phenomenon and found a strong linear correlation between hue angle (h*) and lightness (L*) regardless of species and treatment temperature. Figure 7 shows a typical regression analysis of lightness and hue angle of Scots pine exposed to 100 ˚C steam treatment. Similar trends were observed for spruce specimens that are not represented here. On the figure, the solid symbol represents the initial hue and lightness; empty symbols denote the same relations as a function of increasing treatment time from right to left. The high values of coefficients of determination (R^2) between 0.9 and 0.99 for both species confirm that not only black locust but softwoods have associations between their lightness and hue.

CONCLUSIONS

Methodology and results of the research devoted to exploring the potential of steam treating were outlined. Spruce and Scots pine specimens were exposed to steam treatment of 70 to 100˚C for time periods within the range 0 to 22 days. The different exposures initiated a variety of colour changes of the examined softwoods, mostly similar to the colours of naturally aged indoor objects. The conclusions of this work may be summarized as follows:

1. The lightness of softwoods (L*) decreases rapidly in the initial phase of exposure to steam (first 2 to 5 days), except when exposed to low-temperature steaming (70 ˚C).
2. Redness (a*) increases during the initial phases, and after ten to fifteen days of treatments it tends to be stabilised.
3. The changes of yellow coordinates (b*) suggest a possible washing away effect of steam above the 90 ˚C treatment temperature. This phenomenon needs further investigation.
4. It has been verified that there is a strong correlation between colour hue and lightness of the studied gymnosperms.
5. The developed database and the graphical representations have practical values. These can be used to identify optimum steaming parameters. Once a desired set of colour coordinates has been established, by selecting the appropriate steaming parameters, the current expensive trial and error practices may be avoided or at least reduced. Furthermore, steam-treated softwoods may be used to manufacture replicated historical furniture, joinery constructions, and other artefacts.

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