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COLOUR CHANGES IN BEECH WOOD MODIFIED WITH ESSENTIAL OILS DUE TO FUNGAL AND AGEING-FUNGAL ATTACKS WITH *CONIOPHORA PUTEANA*

*Fungal attacks on beech wood (*Fagus sylvatica *L.) samples (25 × 25 × 3) mm were performed using the brown-rot fungus Coniophora puteana over a period of 8 weeks, without or with their previous accelerated ageing in a Xenotest and a drying oven. Due to the fungal and ageing-fungal attacks, respectively, the top surfaces of the reference beech samples obtained a darker yellow-red shade according to the CIE-$L^*a^*b^*$ colour system. Similar changes in the colour coordinates L^*, a^*, and b^* were found for the beech wood modified with the essential oils which were less fungicidal efficient – lavender, sage, tea-tree, and the oil-mixture. On the other hand, the colour changes in the beech wood modified with those essential oils which had a better fungicidal efficiency – birch, clove, oregano, sweet flag, savory, and thyme – were less significant, confirmed by Duncan's test. Linear correlations with greater or lesser significance were established between the changes in the colour parameters (ΔL^*; Δa^*; Δb^*; ΔE^*) and the corresponding mass losses (Δm) of attacked beech wood, the best for positive Δb^* which identified its yellowing.*

Keywords: beech wood, essential oils, brown-rot, colour

Introduction

Wooden products exposed to exterior conditions, for example, garden furniture or cladding, and also to wet interior conditions, for example, kitchen or bathroom furniture, have to be resistant to ageing and biological damage. It is also important to consider their initial colour after technological treatments with substances (coatings, natural oils, fungicides, etc.) or energy fields (laser, plasma, etc.), and their colour stability during exposure.

Due to weathering, the initial colours of wood surfaces are changed mainly under the influence of sunlight, oxygen, water and dirt [Evans 2008]. Decay

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processes in the polysaccharide, lignin and extractive components of the wood also cause significant changes in its colour [Schmidt 2006]. In practice, the colour stability of wood is usually increased with paints containing UV-absorbents, UV-screeners, pigments, fungicides, or other additives [Forsthuber et al. 2013].

Nowadays the protection of wooden products against wood-decay fungi, which cause loss of strength, aesthetical defects, etc., is given through: (1) chemical preservation with synthetic or natural fungicides; (2) modifications – thermal, chemical (acetylation, furfurylation, etc.), and biological (*Trichoderma* species, etc.); and, preferably, (3) their exposure to dry conditions [Reinprecht 2013].

To the most prospective natural fungicides and modification agents for wood protection belong mainly chitosan [Chittenden et al. 2004] and some essential oils or extractives from plants and durable wood species. They have more advantages: (1) permanent recoverability in nature; (2) acceptable ecological parameters and healthiness; and (3) the usually easier liquidation of the treated wooden products after their service life.

The efficiency of essential oils against wood-destroying fungi, wood-staining fungi and moulds has been researched in more experimental work [Voda et al. 2003; Wang et al. 2005; Kartal et al. 2006; Yang, Clausen 2006; Maoz et al. 2007; Dongmo et al. 2008; Chittenden, Singh 2011; Reinprecht et al. 2013; Su et al. 2013; Pánek et al. 2014]. Generally, the best anti-fungal efficiency has been found for those essential oils which contain phenolic compounds such as carvacrol (oregano, savory), thymol (thyme) or eugenol, as well as for oils with oxygenated compounds such as elemol and cinnamaldehyde (cinnamon), and for geranium oil.

The aim of this work was to analyse the colour changes in nondurable beech wood modified with ten essential oils (birch, clove, lavender, oregano, sweet flag, sage, savory, tea-tree, thyme, and an oil-mixture) due to fungal or combined ageing-fungal attacks. The hypothesis proposed that the colour changes would indicate which essential oils should be more efficient against wood rot in a humid, unsterile environment.

Material and methods

Wood

Beech (*Fagus sylvatica* L.) wood samples with the dimensions 25 × 25 × 3 mm (longitudinal × tangential × radial), without false heart, biological damage, knots or other growth inhomogeneities, were used in the experiment. The sterilization of the samples before treatment with essential oils was performed at a temperature of 103 ±2°C/4 h, and before the fungal attacks with a 30 W germicidal lamp (Chirana, Slovakia) from a distance of 1 m at a temperature of 22 ±2°C/0.5 h, respectively.

Essential oils for wood modification

Selected pure essential oils of pharmacopoeia quality were used for the modification of the beech wood samples (table 1). They were dipped for 24 h in 10% (by mass) ethanol solutions of the individual essential oils at 100 kPa and 20°C.

Table 1. Essential oils used in the experiment

Common name	Scientific name	Major effective components
Birch	*Betula pendula*	Methyl salycilate (99%)
Clove	*Syzygium aromaticum*	Eugenol (82%), Caryophyllene (16.5%)
Lavender	*Lavandula angustifolia*	Linalylacetate (37.1%), Linalool (33.6%), Terpinen-4-ol (2.6%)
Oregano	*Origanum vulgare*	Carvacrol (71.8%), Thymol (5%), gamma-Terpinene (4.5%)
Sweet flag	*Acorus calamus*	Cis-isoasarol trimethylether (78%)
Savory	*Satureja hortensis*	gamma-Terpinene (41.3%), Carvacrol (31.6%), p-cymol (13.8%)
Sage	*Salvia officinalis*	alpha-Thujone (26.7%), Camphor (20.2%), 1,8-Cineole (9.6%)
Tea tree	*Melaleuca alternifolia*	Terpinen-4-ol (42.2%), gamma-Terpinene (20.8%), alpha-Terpinene (9.8%), 1,8-Cineole (3.6%)
Thyme	*Thymus vulgaris*	Thymol (41.3%), p-cymol (22.6%), gamma-Terpinene (7.7%), Carvacrol (2.9%)
Oil mixture 1:1:1:1:1 (by mass) of Sage, Thyme, Eucalypt, Lavender, Lemon	*Salvia officinalis, Thymus vulgaris, Eucalyptus globulus, Lavandula angustifolia, Citrus limon*	alpha-Thujone (5.3%), Thymol (8.2%), 1,8-Cineole (18.3%), Linalool (7.8%), Linalylacetate (7.4%), Limonene (14.2%), p-cymol (4.5%)

Source of essential oils: Nobilis Tilia s.r.o., Czech Republic

Wood-destroying fungus

The brown-rot fungus *Coniophora puteana* (Schumacher ex Freis) Karsten, strain BAM Ebw. 15 (Bundesanstalt für Materialforschung und – prüfung, D-12205 Berlin) was used for the decay attack on the modified and reference samples.

Accelerated ageing

Accelerated ageing of the modified and reference beech samples was performed in the following sequence: (1) 1 week (168 h) in the Xenotest Q-SUN Xe-1-S (Q-Lab Corporation, USA) equipped with a 1800 W xenon lamp and spray section of redistilled water, using an exposure cycle according to the modified standard

EN 927-6 [2006]: 1st Step → 24 h at 45 ±3°C and 2nd Step → 48 sub-cycles each lasting 3 h (2.5 h = UV irradiance 0.55 Wm^{-2} instead of 0.89 Wm^{-2} at 340 nm, and temperature on black panel 50 ±3°C instead of 60 ±3°C; 0.5 h = water spray at 20 ±1°C); and then (2) heating in a drying oven for 8 hours at 103 ±2°C.

Fungal attack

Fungal attacks on the un-aged and artificially-aged beech samples with the brown-rot fungus *Coniophora puteana* were performed according to the modified standard EN 113 [1996], with these changes: a smaller dimension of samples, 25 × 25 × 3 mm instead of 50 × 25 × 15 mm; another treatment process (dipping instead of vacuum impregnation); a shorter time of decay (8 weeks instead of 16 weeks). After the fungal attacks, that is, before the colour analyses and determination of the mass losses, the fungal mycelia were carefully brushed from the top surface (25 × 25 mm) of each sample with the aim of retaining the "new" colour. The top surfaces of the samples – on which the colour analyses were performed – (1) on ageing in the Xenotest had been directly exposed to the UV and visible light, and also to water; (2) during fungal attack had not been in contact with the agar-malt inside Petri dishes.

Colour analyses

The colours of the wood surfaces were analysed according to the CIEL$^*a^*b^*$ system using a CR-10 Color Reader (Konica Minolta, Japan). The Color Reader had a CIE 10° standard observer, CIE standard illuminant D65, sensor head with a diameter of 8 mm, and a detector with 6 silicon photocells. The colour coordinates L^*, a^*, b^* of the natural, modified, aged, fungal-attacked or aged-fungal-attacked beech samples were measured in the centre of their top surfaces (25 × 25 mm), in a conditioned state at ca. 12% EMC. The total colour differences ΔE^* were computed by eq. 1 [CIE 1986]:

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

where: L^* – lightness from 100 (white) to 0 (black),
a^* – the chromaticity coordinate + a^* red or – a^* green,
b^* – the chromaticity coordinate + b^* yellow or – b^* blue,
Δ – the change between the final (aged, fungal-attacked, or aged-fungal-attacked) and initial (modified with oils) state.

Mass losses

After fungal and aged-fungal attacks, respectively, the mass losses Dm in % caused with the brown-rot fungus *Coniophora puteana* were determined for all the reference beech samples and those modified with essential oils [Pánek et al. 2014].

Statistical evaluations

The results of the colour analyses were evaluated on the basis of the mean values, standard deviations, and statistically using Duncan's test (Statistica 10). Linear correlations (Microsoft Excel) were then determined between the colour changes and the mass losses of fungal-attacked or aged-fungal-attacked beech samples.

Results and discussion

Colours of beech wood modified with essential oils

The colour parameters L^*, a^* and b^* in the beech wood modified with the essential oils did not significantly differ from those of the reference unmodified beech (table 2). This was confirmed by Duncan's test (table 2).

Table 2. Colour parameters L^*, a^* and b^* in beech (*Fagus sylvatica*) wood modified with essential oils

Essential oil in beech	L^*			a^*			b^*		
	1	2	3	1	2	3	1	2	3
Birch	66.3	(2.54)	c	7.7	(1.24)	d	17.4	(1.42)	d
Clove	67.5	(2.23)	d	9.2	(0.98)	c	17.3	(0.98)	d
Lavender	66.9	(2.77)	d	8.8	(1.16)	d	16.7	(1.22)	d
Oregano	66.9	(2.21)	d	9.2	(0.77)	c	17.1	(1.10)	d
Sweet flag	67.9	(2.88)	d	7.7	(0.88)	d	16.2	(1.08)	d
Savory	66.9	(2.14)	d	8.5	(0.91)	d	15.8	(1.32)	d
Sage	67.6	(2.90)	d	8.2	(1.37)	d	16.2	(1.42)	d
Tea-tree	67.5	(2.69)	d	9.2	(1.01)	d	17.3	(0.85)	d
Thyme	67.8	(1.99)	d	8.1	(0.86)	d	16.2	(1.61)	d
Oil-mixture	70.3	(3.05)	d	7.3	(1.44)	d	16.4	(1.83)	d
Reference – unmodified beech	68.7	(2.22)	–	7.6	(1.06)		15.3	(2.18)	–

1) Mean values from 12 samples
2) Standard deviations
3) Duncan's test in relation to the reference at the 99.9% significance level (a), the 99% significance level (b), the 95% significance level (c), and without an evident significant difference at $p \geq 0.05$ (d)

Colours of modified beech wood after accelerated ageing

As a result of only the accelerated ageing, carried out in the Xenotest Q-SUN Xe-1-S and a drying oven, the colour changes ΔL^*, Δa^*, Δb^*, and ΔE^* in the beech wood modified with the essential oils in most cases did not differ from those of the reference. This was confirmed by Duncan´s test, in which between the two groups "modified with oils" versus "reference", mostly no significant differences were found (table 3). All the modified and reference beech samples following exposure to the UV-light obtained a yellower shade, with the positive Δb^* from 4.6 with the use of oregano oil to 6.7 with the use of clove oil or no oil (reference). Other colour parameters, the ΔL^* and Δa^*, changed within a very small range from −2.1 to 0.9, with only the beech wood modified with clove oil acquiring an evidently darker tone ($\Delta L^* = -4.9$).

Table 3. Colour changes in beech wood modified with essential oils due to accelerated ageing

Essential oil	ΔL^*			Δa^*			Δb^*			ΔE^*		
	1	2	3	1	2	3	1	2	3	1	2	3
Birch	−1.8	(3.25)	d	0.3	(1.21)	c	4.9	(1.44)	c	6.1	(1.77)	d
Clove	−4.9	(2.11)	a	0.5	(1.52)	b	6.7	(1.50)	d	8.5	(2.36)	d
Lavender	0.9	(2.50)	d	−1.7	(0.95)	d	5.3	(1.26)	d	6.2	(1.20)	d
Oregano	−0.4	(1.98)	d	−2.1	(1.09)	c	4.6	(1.92)	c	5.7	(1.47)	c
Sweet flag	−1.6	(2.75)	d	−0.2	(1.09)	d	5.1	(1.50)	d	6.0	(1.82)	d
Savory	−0.6	(2.06)	d	−1.3	(1.13)	d	5.6	(1.12)	d	6.2	(1.00)	d
Sage	−0.2	(2.21)	d	−0.8	(1.03)	d	6.1	(2.33)	d	6.7	(2.19)	d
Tea-tree	0.0	(2.79)	d	−1.2	(1.12)	d	5.4	(1.11)	d	6.3	(1.10)	d
Thyme	−0.5	(2.53)	d	−1.0	(0.96)	d	5.6	(2.18)	d	6.3	(2.17)	d
Oil mixture	−0.6	(1.65)	d	−0.6	(0.83)	d	5.6	(1.80)	d	6.1	(1.47)	d
Reference	−0.9	(3.68)	–	−1.0	(1.65)	–	6.7	(2.87)	–	7.6	(3.36)	–

1) Mean values from 6 samples
2) Standard deviations
3) Duncan's test in relation to the reference at the 99.9% significance level (a), the 99% significance level (b), the 95% significance level (c), and without an evident significant difference at $p \geq 0.05$ (d)

Generally, following the short artificial weathering, no negative or positive effects of the essential oils on the colour stability of the beech wood were observed. The surfaces of both – the natural and oiled – beech samples obtained a yellower shade. However, in practice, it should be noted that with an extended period of outdoor weathering, it is likely that a greying of the beech surfaces treated or untreated with essential oils will occur, owing to the washing out of the yellow depolymerized and more polar parts of the lignin, and also due to the adsorption of pollutants [Evans 2008].

Colours of modified beech wood after fungal-attacks and ageing-fungal-attacks with *Coniophora puteana*

The wood substance due to degradation with brown-rot fungi obtains darker, yellower and browner shades [Bech-Andersen 1995]. The intensity of such colour changes depends on a number of factors: the species of wood, the species of brown-rot fungus, the type of fungicide or modification agent present in the wood, the ageing history of the wood before its fungal attack, cellulolytic and other bio-mechanisms of decay, the degree of decay, the uniformity of decay, the colour of the fungal mycelia, the distribution of the fungal mycelia in cells of wood, etc.

Table 4. Colour changes in beech wood modified with essential oils due to fungal attack with *Coniophora puteana*

Essential oil	ΔL^*			Δa^*			Δb^*			ΔE^*		
	1	2	3	1	2	3	1	2	3	1	2	3
Birch	−3.0	(2.40)	a	2.1	(0.70)	d	4.2	(1.89)	a	6.1	(1.49)	a
Clove	−6.4	(1.68)	b	1.0	(0.72)	d	2.2	(0.94)	a	7.0	(1.59)	a
Lavender	−17.2	(2.21)	a	3.4	(0.81)	d	6.6	(1.83)	a	18.9	(1.72)	d
Oregano	−4.4	(1.97)	a	−0.2	(0.80)	b	1.1	(0.83)	a	4.7	(1.98)	a
Sweet flag	−2.6	(2.06)	a	1.3	(0.90)	d	2.8	(1.24)	a	4.3	(1.95)	a
Savory	−3.8	(1.84)	a	0.3	(1.01)	c	2.0	(1.15)	a	4.6	(1.57)	a
Sage	−10.9	(2.69)	d	3.9	(0.33)	d	8.4	(1.57)	a	14.5	(1.71)	d
Tea-tree	−11.9	(2.30)	d	3.4	(0.59)	d	8.1	(1.52)	a	14.9	(1.88)	d
Thyme	−4.9	(1.34)	a	0.7	(1.27)	d	1.5	(0.98)	a	5.4	(1.30)	a
Oil mixture	−10.0	(2.76)	d	4.6	(1.09)	c	9.1	(1.82)	b	15.2	(2.46)	d
Reference	−9.1	(2.23)	–	2.5	(1.96)	–	12.8	(3.85)	–	16.0	(2.34)	–

1) Mean values from 6 samples
2) Standard deviations
3) Duncan's test in relation to the reference at the 99.9% significance level (a), the 99% significance level (b), the 95% significance level (c), and without an evident significant difference at $p \geq 0.05$ (d)

As a result of the brown-rot fungus *Coniophora puteana* activity the surfaces of the reference beech wood and the beech modified with essential oils, acquired greater or lesser colour changes ΔL^*, Δa^*, Δb^*, and ΔE^* (table 4). The colours changed the most in the reference beech ($\Delta L^* = -9.1$, $\Delta a^* = 2.5$, $\Delta b^* = 12.8$, and $\Delta E^* = 16.0$), and also in the beech modified with lavender oil, sage oil, tea-tree oil, and the oil-mixture ($\Delta L^* =$ from −10.0 to −17.2, $\Delta a^* =$ from 3.4 to 4.6,

Δb^* = from 6.6 to 9.1, and ΔE^* = from 14.5 to 18.9). On the other hand, the colour changes in the beech wood modified with other oils – birch, clove, oregano, sweet flag, savory, and thyme – were apparently lower (ΔL^* = from −2.6 to −6.4, Δa^* = from -0.2 to 2.1, Δb^* = from 1.1 to 4.2, and ΔE^* = from 4.3 to 7.0). This was also confirmed by Duncan's test (table 4).

Similar tendencies relating to the colour changes in the surfaces of the beech samples were found following a combination of the accelerated ageing (in the Xenotest Q-SUN Xe-1-S and a drying oven) and the decay attack with *Coniophora puteana* (table 5).

Table 5. Colour changes in beech wood modified with essential oils due to combination of accelerated ageing and fungal attack with *Coniophora puteana*

Essential oil	ΔL^*			Δa^*			Δb^*			ΔE^*		
	1	2	3	1	2	3	1	2	3	1	2	3
Birch	−4.6	(2.89)	a	3.6	(1.34)	d	9.3	(1.84)	d	11.4	(1.66)	a
Clove	−11.6	(2.79)	d	1.7	(2.32)	c	6.2	(1.91)	a	12.1	(1.27)	b
Lavender	−10.8	(2.85)	d	3.2	(1.13)	d	9.9	(2.14)	d	15.2	(2.88)	d
Oregano	−7.1	(1.75)	a	−1.1	(1.37)	a	5.9	(2.00)	a	9.6	(1.79)	a
Sweet flag	−5.5	(2.09)	a	2.5	(0.93)	d	10.3	(1.41)	d	12.2	(0.73)	b
Savory	−6.8	(1.73)	a	0.4	(1.49)	a	8.2	(0.61)	d	10.8	(1.16)	a
Sage	−9.2	(2.07)	c	3.8	(1.54)	d	10.4	(2.81)	d	15.5	(1.64)	d
Tea-tree	−12.3	(3.00)	d	2.9	(0.98)	d	9.5	(1.70)	d	16.9	(2.17)	d
Thyme	−4.6	(2.38)	a	−0.7	(0.84)	a	4.8	(2.15)	a	7.0	(2.28)	a
Oil-mixture	−13.1	(1.49)	d	5.3	(2.04)	d	10.8	(2.13)	d	17.9	(2.45)	d
Reference	−13.0	(1.15)	–	3.8	(1.93)	–	10.8	(2.42)	–	15.9	(4.49)	–

1) Mean values from 6 samples
2) Standard deviations
3) Duncan's test in relation to the reference at the 99.9% significance level (a), the 99% significance level (b), the 95% significance level (c), and without an evident significant difference at $p \geq 0.05$ (d)

However, all the modified beech samples after the ageing-fungal-attack gained slightly more yellow shade (higher $+\Delta b^*$, and then also higher ΔE^*) in comparison to the beech samples exposed immediately to *Coniophora puteana* – i.e. only after the fungal-attack. This can be explained by their previous yellowing at accelerated ageing (table 3). As a consequence, after the ageing-fungal attack, the positive Δb^* values for the beech samples treated with the fungicidal effective oils (birch, clove, oregano, sweet flag, savory or thyme) and the fungicidal ineffective oils (lavender, sage, tea-tree or the oil-mixture) were within a narrower range from 4.8 to 10.8 (table 5) than those obtained only after fungal attack from 1.1 to 9.1 (table 4).

Connection between colour changes and mass losses of fungal-attacked and aged--fungal-attacked modified beech wood

Brown rot is connected preferentially with the depolymerisation of polysaccharides and the destruction of the secondary layers in the cell walls of wood. The degree of brown rot can be indirectly characterized by the physical and mechanical properties of wood: mass loss; density loss; strength loss; elasticity loss; hardness loss; sorption change; colour change; etc. [Reinprecht 2013].

A comparison of the colour differences (ΔL^*, Δa^*, Δb^*, and ΔE^*) in the fungal--attacked and aged-fungal-attacked beech samples with their mass losses (Δm) was expressed with the linear correlations by eq. 2 (figs. 1 and 2):

$$\Delta\text{Colour parameter} = \text{A} + \text{B} * \Delta m \tag{2}$$

The achieved results indicated:
- a change in the colour of the beech wood even without its deterioration by the brown-rot fungus *Coniophora puteana*, or by accelerated ageing and the subsequent action of this fungus – see the values A from 1.20 at Δa^* to 10.67 at ΔE^* valid for the zero mass loss (figs. 1 and 2); this was probably due to the laboratory test conditions in glass Petri dishes, where stains could be created on the top surfaces of the beech samples due to drops of condensate water and their contact with the essential oils in the samples,
- an existence of certain connections between the mass losses and the darkening, yellowing and redness of the beech wood exposed to the fungus *Coniophora puteana* – see the values B from 0.097 to 0.468, and also the coefficients of determination R^2 from 0.296 to 0.790 (fig. 1),
- the possibility to determine the degree of brown rot in the beech wood by *Coniophora puteana* (fig. 1) based on yellowing of its surfaces (larger positive Δb^*), due to the degradation of the polysaccharides having white colour and the increased proportion of the yellow-brown lignin,
- a less pronounced yellowing of the beech wood due to decay by *Coniophora puteana* in a situation when it was exposed to the combined ageing-fungal attacks – in linear correlations for the Δb^* see higher values A (7.49 instead of 3.01) and lower values B (0.140 instead of 0.384) if the wood samples were firstly subjected to the accelerated ageing (figs. 1 and 2); this can be explained by a significant yellowing of the beech wood during the accelerated ageing, following which, the subsequent yellowing at decay was not so dominant.

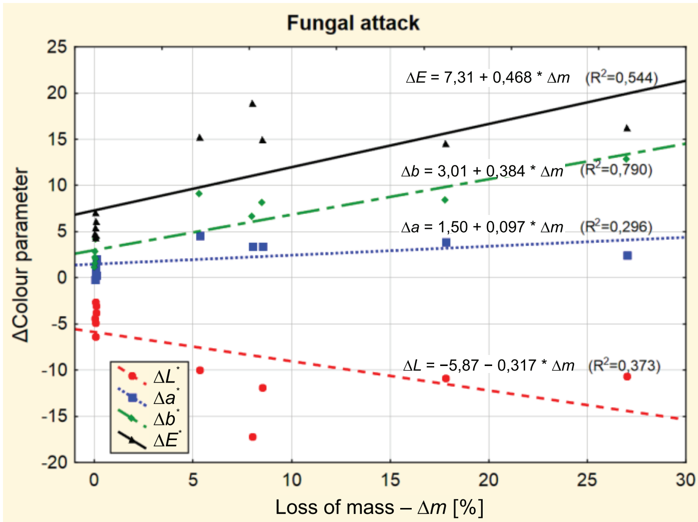

Fig. 1. Correlations between the differences of individual colour parameters (ΔL^*, Δa^*, Δb^*, ΔE^*) and the mass losses (Δm) caused by *Coniophora puteana* for the fungal--attacked beech wood

Note: The mean values of colour parameters (table 4) and mass losses for reference and modified samples are given.

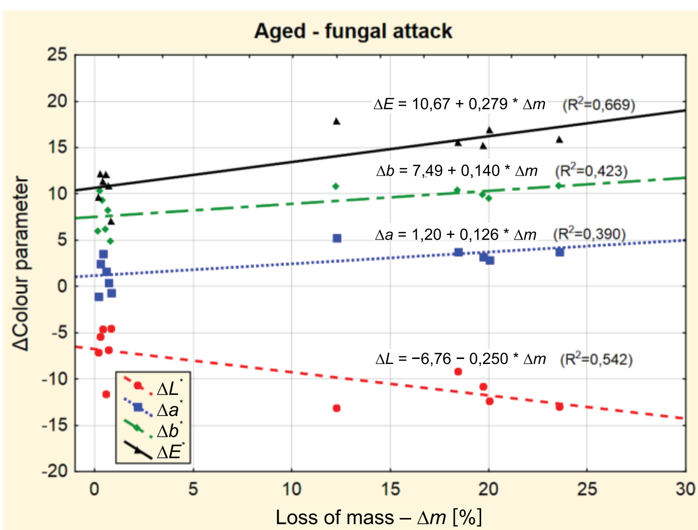

Fig. 2. Correlations between the differences of individual colour parameters (ΔL^*, Δa^*, Δb^*, ΔE^*) and the mass losses (Δm) caused by *Coniophora puteana* for the aged--fungal-attacked beech wood

Note: The mean values of colour parameters (table 5) and mass losses for reference and modified samples are given.

Conclusions

From the achieved results the following conclusions can be stated:

- The accelerated ageing of the beech wood modified with the tested essential oils caused its apparent yellowing (Δb^* values were ca. 6). However, due to 1 week's exposure to UV-light, water and increased temperatures, its other colour parameters changed only slightly (ΔL^* and Δa^* values were from ca. −2 to 1).
- The fungal and combined aged-fungal attacks of the modified beech wood in the presence of the brown-rot fungus *Coniophora puteana* caused its darker yellow-red shades, which were less apparent when the fungicidally more effective essential oils (birch, clove, oregano, sweet flag, savory, and thyme) were used, and more apparent when fungicidally ineffective oils (lavender, sage, tea-tree, and the oil-mixture) were used.
- The presence and degrees of the brown rot in the wooden products could be quickly determined by their colour changes, as these were indicated from the linear correlations between the individual colour parameters (ΔL^*, Δa^*, Δb^*, ΔE^*) and the mass losses (Δm).
- In the linear correlations „colour change = f (degree of decay determined by mass loss)" the yellowing (positive Δb^*) was manifested as the most suitable colour parameter for the identification of wood attack by the brown-rot fungus *Coniophora puteana*. However, following the combined accelerated ageing and fungal attack, the darkening parameter (negative ΔL^*) was more apparent.

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