Utilisation of Winter Rapeseed in Wood-based Materials as a Solution of Wood Shortage and Forest Protection

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Due to various factors, there is evidence that there will be a future lack of wood materials in the woodworking and energy sectors, as well as other sectors. This has been confirmed definitively through the most recent developments. Possible solutions include the partial replacement of wood in composite materials by post-harvest remnants of agricultural crops. Unlike wood matter, however, these stems need surface pre-treatment before they can be used to produce composite materials. In this study the effects were compared for two pre-treatments of stems (alkaline and hydrothermal) of rapeseed (*Brassica napus* L.), maize (*Zea mays* L.), and wheat (*Triticum aestivum* L.). The effects were compared using the contact angle between water and the surfaces of the stems. Hydrothermal modification yielded a statistically significant reduction in the contact angle between water and the stem surfaces of winter rapeseed and maize; likewise, alkaline modification yielded a statistically significant reduction in the contact angle between water and the stem surface of maize. The possibility of using winter rape to produce composite materials was further evaluated and comprehensively assessed using SWOT analysis.

Keywords: Rapeseed; Wheat; Maize; Straw; Wood; Forest; Surface modification

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INTRODUCTION

Forests are a source not only of goods but also of ecological services and socio-cultural benefits (Stenger *et al*. 2009; Šišák *et al.* 2016). The increased demand for wood, however, can pose a threat to the performance of these non-production functions of forests (Balest *et al. In Press*). Locally and globally, the demand for wood material is increasing, with the greatest needs for its supply, in terms of volume, coming from not only various wood and energy sectors but also from the paper, chemical, and other sectors of national economies (Seintsch 2011; Lauri *et al*. 2012). For example in the Czech Republic, where the production potential of forests is well known (Pulkrab *at al.* 2015), wood-processing companies are facing a shortage of logs even now, with their economic performance declining (Sujová *et al*. 2017). Unfortunately, the growth figures for wood matter are not large enough to meet the ever-increasing demand for its supply (Bostedt e*t al*. 2016). It is estimated that by 2030 there will be an increase of 73% in the demand for wood (compared with 2010), with a shortfall of 316 million m^3 (Mantau *et al*. 2010). To avert the threat of a shortage of wood for industrial use, other actions need to be implemented in cooperation with silvicultural actions, strategies, and measures (Mburu *et al*. 2007; Ye *et al*. 2007; Dieter and Seintsch 2012; Temperli 2017). Legal regulation for the protection of forests appears to be an evident and necessary instrument for coordinating the expected situation.

Comprehensive legislation does not exist within the European Union, even though forest cover accounts for 38% of the surface area of the region. The main reasons for this are the distinct types of geoclimatic diversity and the circumstance that only six member states occupy some two thirds of the total area. This would make any compact European legislation quite extensive or even confusing and, in most member states, impossible to apply in practice. Therefore, member states stipulate the conditions for the protection of forests at the national legislative level (European Parliament 2017). In the Czech Republic, Czech Parliament Act No. 289/1995 (1995) is the main piece of legislation and is further supplemented, in particular, by decrees issued by the Ministry of Agriculture. The main task of the Forest Act is, according to the provisions of its Section 1, to specify the prerequisites for the preservation, management, and regeneration of forests as a national resource while still allowing permanent economic activities in the area; such activities are possible in forests, whether national or private, but compliance with all the conditions for the sustainable development of forests is required.

In the future, demand for wood will continue to increase because of the need to reduce CO_2 emissions and, in particular, to replace energy-consuming materials such as concrete and steel. Another driver of demand will be the goal to eliminate fossil raw materials in both the energy and processing industries, motivated not only by the need to reduce CO_2 emissions but also because deposits of fossil raw materials will gradually become exhausted in the long term (Lauri *et al*. 2012; Temperli *et al*. 2017). This implies that, in addition to forestry and legal measures, which alone cannot fully protect the performance of the non-production functions of forests in the long term, it will be necessary to look for other natural sources of cellulose and lignin. This involves annual and biennial plants because their stems, which also consist of cellulose and lignin, can be utilised for the manufacture of materials (Halvarsson *et al*. 2010; Marinho *et al*. 2013; Hýsek *et al*. 2016) as well as for energy purposes (Haq *et al*. 2016; Taha *et al*. 2016). Post-harvest remnants of agricultural crops appear to be promising materials (Guler *et al*. 2006; Belini *et al*. 2012; El-Kassas and Mourad 2013; Částková *et al*. 2018). Unlike with wood matter. However, the production of composite materials from the stems of agricultural crops typically requires that the surfaces of these stems be pre-treated, in order to disrupt the waxy layer that inhibits high-quality bonding between the particle and the adhesive (Bekhta *et al.* 2013; Částková *et al*. 2018).

Pre-treatment of rapeseed particles by both boiling in water or soaking in NaOH solution led to morphological changes of the particle surface and statistical significant decrease of some elements (Ca, K, Mg, and S) in the particle mass (Částková *et al.* 2018). Bekhta *et al.* 2013 reported that soaking in acetic anhydride solution, as well as boiling in soapy solution or in water enhanced the adhesion between wheat straw particle and urea formaldehyde adhesive, which consequently led to increase of mechanical properties.

This aim of this report is to determine the effects of different types of stem pre-treatment on the surface properties of the stems of rape, maize, and wheat modified in this way. Furthermore, the report seeks to evaluate more comprehensively the possibility of using stems of winter rapeseed for the production of composite materials.

EXPERIMENTAL

Materials

In order to compare the effect of modification on contact angle between stalk surface and water, three kinds of stalks were used: rapeseed (*Brassica napus* L.), maize (*Zea mays* L.), and wheat (*Triticum aestivum* L.). All plants were grown in the Czech Republic in the Central Bohemian Region.

Methods

Two kinds of surface pre-treatment (modification) were tested: hydrothermal modification and alkaline modification. A third group was left untreated as a control. The hydrothermal treatment was carried out by boiling in water for 45 min. In the chemical treatment, the particles were soaked in 2% sodium hydroxide (NaOH) solution at 20 °C for 45 min. After both modifications, particles were carefully flushed with water and then oven dried to 6% moisture content (Částková *et al*. 2018).

To determine the wettability of treated and untreated surface of stalks, the contact angle of the water and stalk surface was measured using a DSA 30E goniometer (Krüss GmbH, Hamburg, Germany). The contact angle was measured only on the exterior surface of stalks. Thirty (30) measurements of static contact angle were made for each straw modification. The volume of each distilled water droplet was 5 µL, with the measurement taken 5 s after the application. Contact angle was measured using image analysis software (Částková *et al*. 2018).

The morphological changes of surface of stalks were observed with a MIRA 3 scanning electron microscope (Tescan Orsay Holding, Brno, Czech Republic) with a secondary electron detector operated at 15 kV acceleration voltage.

To evaluate measured data, descriptive statistics (arithmetic mean, minimum, maximum, standard deviation, and coefficient of variation) were calculated. A two-way analysis of variance was used to determine whether any of the pairwise differences among the various arithmetic means were significant. The Tukey post hoc test was employed to determine the significant differences between group means. Computations were carried out using Statistica 12 software (StatSoft, Tulsa, OK, USA). A significance level of $\alpha = 0.05$ was selected.

An analysis of strengths, weaknesses, opportunities, and threats (SWOT analysis) was made for boards based on oilseed rape stems in order to evaluate the possibilities of using winter oilseed rape for the production of composite materials; it is presented in the Results and Discussion section.

RESULTS AND DISCUSSION

Surface Modification

Table 1 lists the arithmetical averages, minimum and maximum figures, standard deviations, and coefficients of variation for the data sets of measured contact angles between water and the surfaces of three types of plant stems for three surface treatment variants. In accordance with theoretical assumptions, the greatest contact angles between water and the straw surfaces were achieved in untreated stems in all three species of plants. The highest figures were reached for maize; however, the differences between plants were not statistically significant. Both types of modification caused the desired effect, a reduced contact angle between water and the surfaces of the stems. The lowest figures were recorded for maize stems modified in an alkaline environment.

Table 1. Descriptive Statistics of Measured Contact Angle Values

Straw	Modification	Mean (°)	Minimum (°)	Maximum (°)	Standard Deviation (°)	Coefficient of Variation (%)
Rapeseed	Hydrothermal	82.7	68.85	112.70	10.4	12.6
	Alkaline	91.1	79.01	100.90	6.3	6.9
	Untreated	94.1	70.70	109.90	9.6	10.2
Maize	Hydrothermal	83.9	71.59	98.15	6.9	8.2
	Alkaline	76.8	53.39	97.09	8.6	11.2
	Untreated	94.8	79.13	104.82	5.6	5.9
Wheat	Hydrothermal	89.6	70.73	108.50	11.4	12.8
	Alkaline	85.0	69.42	98.41	7.7	9.1
	Untreated	91.3	62.40	107.05	10.8	11.8

The two-factor analysis of variance shown in Fig. 1 depicts the relationship between the contact angle and the type of stem or surface treatment; Table 2 shows the statistical significance for pairwise differences. The results show that the hydrothermal modification significantly reduced the contact angle between the water and the surfaces of the maize and rape stems. Alkaline modification, in contrast, yielded a statistically significant reduction in contact angle in maize stems only. Using a 0.05 level of significance, alkaline modification of wheat stems did not have a statistically significant effect on the contact angle. Modification by sodium hydroxide solution did reduce the contact angle between water and rape stems, but this difference was not statistically significant either. For rape straw, hydrothermal modification seems to be a suitable type of surface treatment, based on these results. For maize stems, alkaline modification can be used in addition to the hydrothermal variant; however, if a cheaper variant is preferred, hydrothermal modification would be sufficient. From the results obtained, the selected types of modification seem to be inappropriate for modification of the surface of wheat straw.

The contact angle generally presents a high variability among plant materials (Oberhofnerová and Pánek 2016), and increased variability is also evident from the results obtained in this work. The considerable variability of the measured data, unfortunately, caused some of the rather large differences to be statistically insignificant. For example, no statistically significant difference between hydrothermal and alkaline modifications was demonstrated for maize stems, and no influence of modification at all was demonstrated for the contact angle of wheat straw.

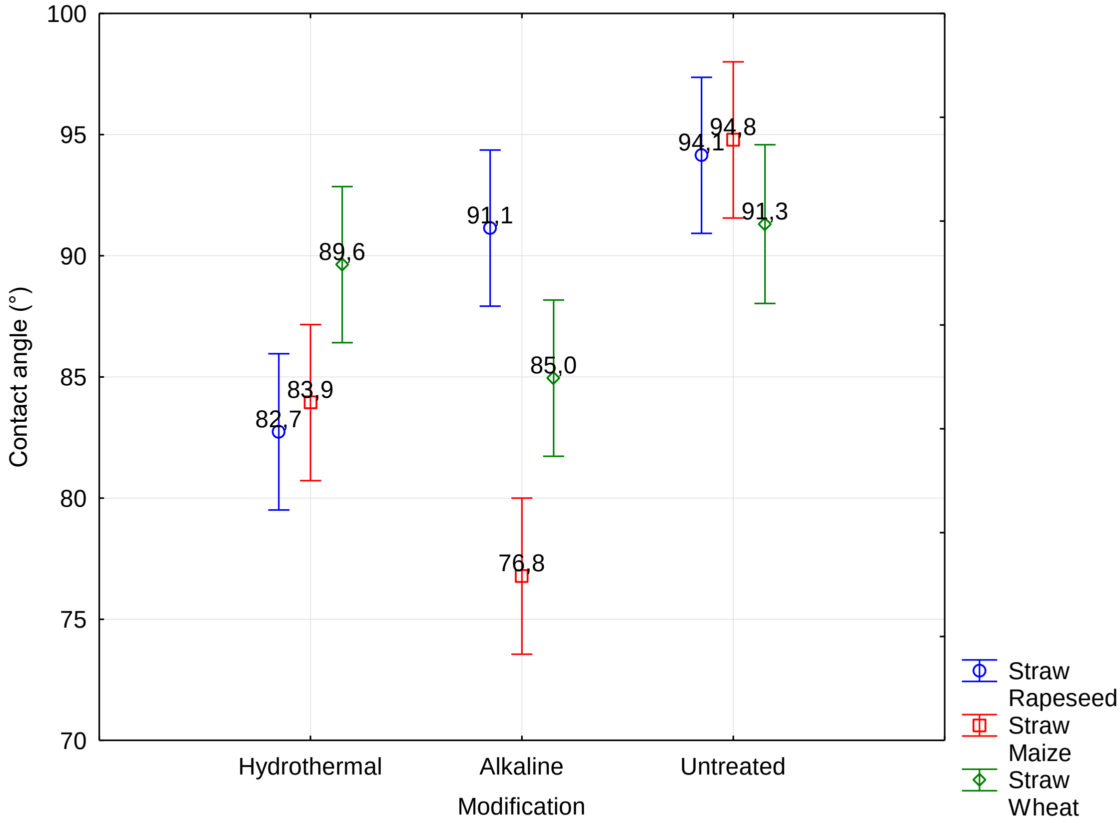


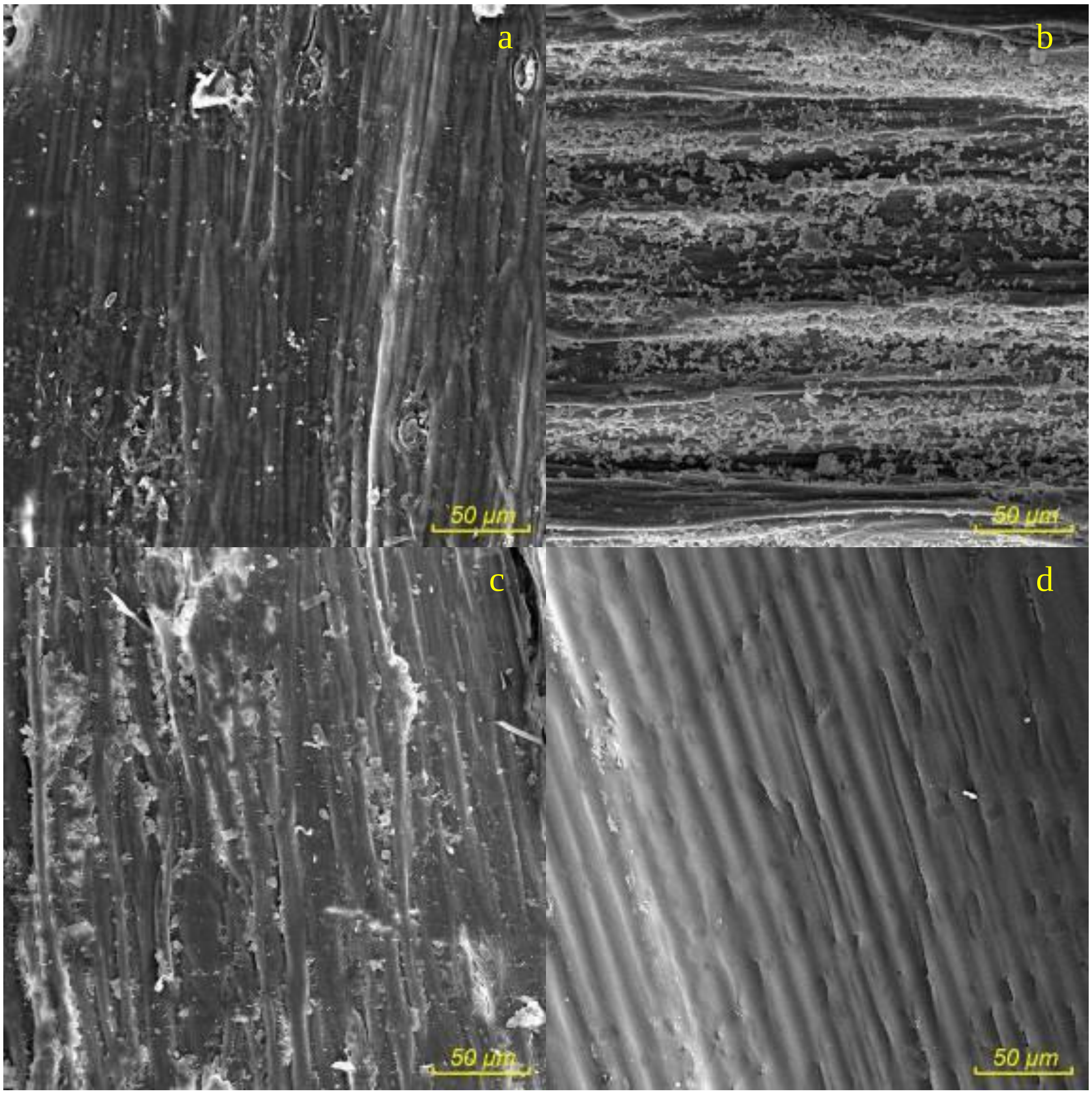
Fig. 1. ANOVA – effect of straw and modification on contact angle (Note: vertical bars depict 95% confidence intervals)

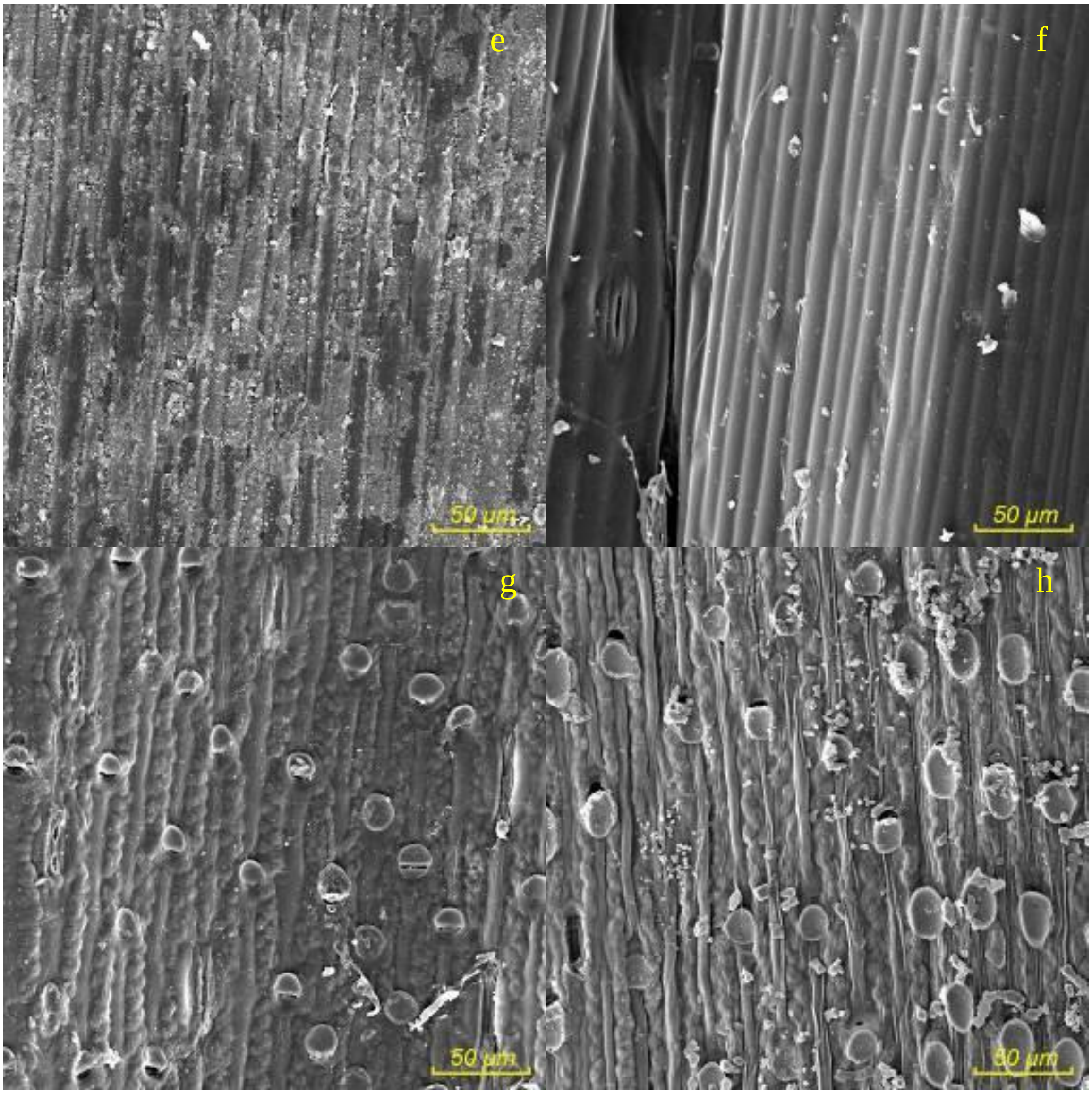
Table 2. Appropriate Statistical Significances of Differences in Fig. 1

	Straw	R	R	R	M	M	M	W	W	W
Straw	Modification	H	A	U	H	A	U	H	A	U
R	H		s.	s.	n.s.	n.s.	s.	n.s.	n.s.	s.
R	A	s.		n.s.	s.	s.	n.s.	n.s.	n.s.	n.s.
R	U	s.	n.s.		s.	s.	n.s.	n.s.	s.	n.s.
M	H	n.s.	s.	s.		n.s.	s.	n.s.	n.s.	s.
M	A	n.s.	s.	s.	n.s.		s.	s.	s.	s.
M	U	s.	n.s.	n.s.	s.	s.		n.s.	s.	n.s.
W	H	n.s.	n.s.	n.s.	n.s.	s.	n.s.		n.s.	n.s.
W	A	n.s.	n.s.	s.	n.s.	s.	s.	n.s.		n.s.
W	U	s.	n.s.	n.s.	s.	s.	n.s.	n.s.	n.s.	

Note: R = Rapeseed, M = Maize, W = Wheat; H = Hydrothermal, A = Alkaline, U = Untreated; s. = significant, n.s. = not significant

In Fig. 2a-i are depicted morphological changes of rapeseed, maize and wheat stalks after different modifications. It can be seen that both hydrothermal and alkaline modification caused visible changes in the surface structure of stems. In Figs. 2g-h one can observe loss of the top layer (epidermis) of the wheat stem surface. Pores of untreated stems are sunk in the top layer, whereas pores of modified stems are protruding, because the top layer is missing. Maize stalks exhibited visual changes of stem surface only after alkaline treatment. The damage of maize stem surface by hydrothermal treatment was not visible, despite the fact that the decrease of water contact angle was significant. It can be assumed that boiling water did not cause any morphological changes of the maize surface, but only washed the stems and thus the water contact angle was lower. Also any damage of rapeseed stem surface was caused by hydrothermal treatment. Rapeseed stems evidenced changes of surface only after alkaline modification. On the rapeseed, maize and wheat stems were deposited crystals of Ca after alkaline treatment. These crystals were precipitated by sodium hydroxide (Částková *et al*. 2018).

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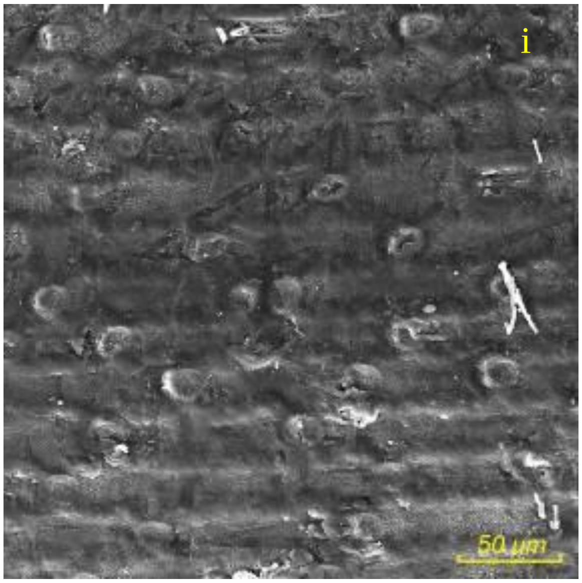

Fig. 2. Electron micrographs of rape, maize and wheat straw surfaces (magnification 1000x). (a) Hydrothermal modified rape stalk, (b) alkaline modified rape stalk, (c) untreated rape stalk, (d) hydrothermal modified maize stalk, (e) alkaline modified maize stalk, (f) untreated maize stalk, (g) hydrothermal modified wheat stalk, (h) alkaline modified wheat stalk, and (i) untreated wheat stalk

Scientific reports that evaluate the possibility of using post-harvest remnants of crops have focused mainly on the characteristics of the material produced. If, however, the present results are to be commercialised, then the issue of producing composite materials from these crops needs a more comprehensive assessment. Therefore, the strengths, weaknesses, opportunities, and threats of the production of particle board from rape stems were analysed. Stems of winter rapeseed were selected as a promising material, with their production amounting to about 42 million tonnes per annum in the European Union (Eurostat 2016); unlike stems of wheat and maize, however, they have not yet found any considerable application. In the European Union, 29.1 million m^3 of particle board was produced in 2015 (EPF 2017). Therefore, the current rape stem production already has the potential to replace almost two times the wood used in particle boards in the EU (ca. 0.75 tonnes of raw materials are required to produce 1 m^3 of particleboards). The possibility of successful replacement of wood in wood-based materials by rapeseed stems has already been demonstrated (Dziurka *et al.* 2015; Dukarska *et al.* 2017), and the effect of rapeseed particle pre-treatment by hydrothermal and alkaline treatment on the disrupting of the surface layer has also already been estimated and reported (Částková *et al.* 2018).

SWOT Analysis of Making Particle Board from Rape

Strengths

- **Low purchasing costs (waste not used):** Rape stems are currently not used; they are turned to chips during harvest and left on the field or used for energy purposes at the most (Karaosmanoğlu *et al*. 1999; Zabaniotou *et al*. 2008; Díaz *et al*. 2009). As this involves unused harvest remnants, low purchasing costs can be assumed.
- **Widespread availability:** In 2017, there was in The Czech Republic a total of 407 thousand hectares of land sowed with rape, which represents 16.5% of the total

sowing area of this country (CSO 2017). For stems, yield per hectare in Europe is 3 to 10 t/ha, meaning that in 2014 the European Union produced around 42 million tonnes of stems (Eurostat 2016). Widespread availability and huge produced amounts of rape stems are reported from all over the word, as from China (Huang *et al.* 2016), Poland (Dukarska *et al.* 2017), Iran (Yousefi 2009), Canada and United States (Oh and Jamaludin 2015).

- **Renewable resource:** It is a renewable resource that can be harvested annually to source lignin and cellulose (Karaosmanoğlu 1999).
- **Policies of the EU and the Czech Republic:** European Union policy supports sowing large areas of winter oilseed rape, meaning that the crop is highly financially advantageous for farmers. The European Union has set itself an objective (European Parliament (EP) Directive 2009/28/EC 2009) to reduce greenhouse gas emissions by 20% compared with the values in 1990. In addition, a directive was adopted (European Parliament (EP) Directive 98/70/EC 1998) concerning fuel quality that tasks fuel suppliers to reduce, by 2020, the intensity of greenhouse gas emissions in fuel mixtures by 6% in comparison with 2010; this provides an incentive for more extensive use of low-carbon fuels in transportation. Because most of this 6% consists largely of rape, there is an assumption of high consumption of rape (European Commission (EC) Report COM(2017) 284 2017). This issue is also elaborated at the national level; the mandatory content of mineral oil is governed by Czech Parliament Act No. 353/2003 (2003), where it is established that a mixture of medium oils and heavy gas oils shall contain at least 30% methyl ester of rapeseed oil (§ 45(2)(c)). Despite the fact that in the European Union 2nd generation biofuels are regarded as having better prospects, in the Czech Republic biofuels 1st generation from rapeseed are highly supported, the financial concession can be found in the excise taxes (Act No. 353/2003 (2003).
- **Good mechanical and physical properties:** The chemical composition of stems and the dimensions of rape fibres are similar to those of the wood of broad-leaf trees (Adapa *et al*. 2009; Tofanica *et al*. 2011). The characteristics of composite materials made of this raw material are comparable with commercially available products based on wood (Huang *et al*. 2016; Nikvash *et al*. 2012; Dziurka *et al*. 2015; Dukarska *et al*. 2017).
- **The existing technology of particle and fibre boards can be leveraged:** Given the similarities in the composition of rape fibres and particles and those of wood, existing board production technology could presumably be utilised after modifications.
- **Stems can be compressed for storage:** Stems of annual and biennial plants contain pulp, allowing compression of the straw into bales for transportation, handling, and storage.
- **Annual cycle of rape cultivation:** The annual cycle of the cultivation of winter oilseed rape (Su *et al*. 2014), and the consequent production of straw, is an important benefit permitting rapid response to changes in the market.
- **Low energy intensity of production:** The bulk density of rape straw is around 270 kg/m^3 for 10% moisture content; the particle density is 1,550 kg/m^3 (Adapa *et al*. 2009). Compared with wood, which has a significantly higher density, the stems are easier and require less energy to disintegrate (Zhu and Pan 2010).

- **CO_2 emissions reduction:** Unlike burning stems in solid form or using them for biofuel production, making boards binds CO_2 in the product for several decades (Schlamadinger and Marland 1996).

Weaknesses

- **Variability of the properties:** The properties of natural materials exhibit higher variability compared with artificial materials (Anandjiwala and Blouw 2007; Das *et al*. 2012; Hýsek *et al*. 2016).
- **Soaking and moistening capacity:** With free hydroxyl groups contained in the cellulose fibres, rape fibres can absorb molecules of water from both the air and liquid water (Hofstetter *et al*. 2006), which in turn influences the properties of soaking and moistening of materials produced from these fibres. In composite materials, however, soaking and moistening capacity can be substantially reduced by appropriate adhesives and additives (Dukarska *et al*. 2017).
- **The technology of collecting straw from fields is not fully developed:** Currently, winter oilseed rape stems are being turned into chips when harvested and left lying in the fields. For collecting stems, it would be appropriate to use collecting and packaging units that are already being used for collecting post-harvest remnants of other crops (Carvalho *et al*. 2017; Tang *et al*. 2017).
- **Production technology is not fully developed:** Boards made of rape particles are not yet commercially produced, though research is currently underway, with objectives including the development of board production technology. In the case of water-assisted particle pre-treatment, waste water management could raise costs of this production.
- **Demand for environmentally friendly products still low:** Demand for environmentally friendly products is rising, yet only a quarter (26%) of the EU population “often buy environmentally-friendly products” (Flash Eurobarometer 2013).
- **Drawing nutrients from the soil:** Compared with ploughing stems into the soil, nutrients are removed from the soil, with the subsequent need for fertilising using inorganic fertilisers (Su *et al*. 2014). However, the straw still needs to be ploughed into the soil for the nutrients to be absorbed. Through the widely used practice of shallow ploughing, instead of deep ploughing, the quantity of nutrients absorbed is significantly reduced (Su *et al*. 2015; Zhu *et al*. 2016).
- **Bulkiness of the raw material:** Pulp represents a substantial portion of the stem. Due to the pulp, the density of the stems is 270 kg/m^3 for approximately 10% humidity, and bulkiness is greater in comparison with wood (Adapa *et al*. 2009).
- **Degradation by biotic factors:** Stems of rape can degrade through the action of biotic factors when stored improperly, as can any other natural lignin-cellulose material (Anandjiwala and Blouw 2007; Das *et al*. 2012).
- **Seasonal nature of the harvest:** Given the seasonality of the harvest (Tofanica *et al*. 2011), it is necessary to put the material into storage in large quantities, with an associated cost.

Opportunities

- **An extensive market of large-area composite materials for construction and furniture-making applications:** In the European Union, 53.8 million m^3 of wood-based, large-area composite materials were produced in 2015 (EPF 2017).
- **Improved economic situation of farmers:** Using straw as a by-product from the production of winter rape provides a significant monetary income to farmers.
- **Addressing the situation of the wood raw materials shortage:** The partial replacement of wood in lignin- and cellulose-based composite materials by winter rape can significantly contribute to addressing the lack of wood in various wood-processing and energy sectors (Ye *et al*. 2007; Dziurka *et al*. 2015). This contributes to protecting the equally important non-production functions of forests as a very important positive externality.
- **Legislative support for environmentally-friendly products:** Support from national governments for environmentally-friendly solutions is assumed in the future and can enhance their propagation in relation to products from non-renewable resources.
- **Low energy consumption in production:** Energy demands for the production of final products made of wood-based composites is significantly lower than for products made from concrete, steel, or glass. It is assumed that the production of boards from rape will use even less energy than production from wood.
- **Expansion into sectors other than just the furniture-making and construction industries:** While the furniture-making and construction sectors are assumed to be the major industries in which products made of rape stems could find applications (in the form of large-area materials), composite materials made of rape stems, such as composites from fibres and shaped moulded pieces, could find applications in automotive, shipbuilding, and other industries.
- **Utilising the stems of plants other than rape:** There could be more than just winter oilseed rape fibres or particles present in the composite materials produced; they could be combined with other natural fibres or particles according to the purpose (Nikvash *et al*. 2012; Oh and Jamaludin 2015).

Threats

- **Competition from composite materials made of other renewable raw materials:** Research is underway, focusing on the use of other renewable raw materials. Possible examples for potential use include bamboo (Marinho *et al*. 2013), sugar cane (Belini *et al*. 2012), reeds (Han *et al*. 2001), flax, hemp, and kenaf (Aisyah *et al*. 2013; Papadopoulou *et al*. 2014).
- **Concrete lobby:** The lobbying activities of conventional construction companies could significantly hamper the propagation of materials based on wood and other natural resources; this currently involves legislative disadvantages and the limits applied to wood structures.
- **Low consumer awareness:** In general, any further growth in production using renewable raw materials in Europe might be prevented through low consumer awareness. In Eastern European countries especially, consumers still prevail who prefer cheaper variants using non-renewable resources to those involving renewable resources.
- **Pests:** As with any other monoculture, fields of rape are at risk of being damaged by pests. As the area of monoculture grows, this threat is increasing, making it necessary

to take agronomic measures. In the case of winter oilseed rape, this involves selective breeding, proper agronomic practices, treatment of crops against pests, and other measures (Zegada-Lizarazu and Monti 2010).

- **Competition from biofuel production:** Producing biofuels provides an alternative to using post-harvest remnants of agricultural crops to produce composite materials; this primarily involves bioethanol production. Raw materials for producing biofuels are also not subject to quality requirements of such a high level as are materials intended for the production of composite materials (Haq *et al*. 2016; Taha *et al*. 2016).
- **Reduced rape production volume:** Any reduced production of winter rape, whether from a change in the policy that currently results in a higher volume of rape production compared with other raw materials or from other factors such as decreased demand for rapeseed oil, poses a significant threat. According to Directive 98/70/EC (1998) on the quality of fuels, the European Commission does not propose extending the reduction of emissions of greenhouse gases through fuels after 2020 (European Commission (EC) Report COM(2017) 284 2017).

CONCLUSIONS

1. Hydrothermal and alkaline modification of the surface of plant stems has an effect on the contact angle between the stem surface and water.
2. Specifically, hydrothermal modification yielded a statistically significant reduction in the contact angle between water and the stem surfaces of winter oilseed rape and maize; likewise, alkaline modification yielded a reduction in the contact angle between water and the stem surface of maize.
3. SWOT analysis suggests that winter rape stems are a very promising material for the production of composites.
4. Partial replacement of wood in wood-based composites with winter rape stems brings positive externalities, one of the most important being a contribution to the protection of the non-production functions of forests.

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