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Sea buckthorn wood processing for solid biofuels

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Declaration

I hereby declare that this thesis entitled ”Sea buckthorn wood processing for solid biofuels” is my own work and all the sources have been quoted and acknowledged by means of complete references.

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Ondřej Novotný

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Abstrakt

Spotřeba energie během posledních let stále roste a identifikace nových zdrojů energie může zlepšit energetickou soběstačnost mnoha regionů. Zbytková biomasa, získávána jako vedlejší produkt zemědělské výroby, může poskytovat významné množství energie pro vytápění nebo výrobu elektřiny. Odpadní biomasa, vznikající v ovocných sadech nebo na plantážích, je jedním z potenciálních zdrojů energie, stejně jako sláma, které je v zemědělství přebytek a jejíž vlastnosti jsou z energetického hlediska problematické. Tato práce hodnotí množství zbytkového dřeva vznikajícího při sklizni Rakytníku řešetlákového (*Hippophae rhamnoides*) v sadech, a možnost jeho využití ve formě briket pro vytápění. Výnosy dřeva byly sledovány v podmínkách České Republiky a brikety vyrobené z tohoto odpadního dřeva byly zhodnoceny podle mezinárodních norem pro tuhá biopaliva. Následně byly vyrobeny kombinované brikety ze směsí z rakytníkového dřeva a pšeničné a řepkové slámy, za účelem zhodnocení vlivu zkoumaného materiálu na technické parametry těchto briket. Výnos suchého odpadního dřeva byl změřen jako 0.93 $t.ha^{-1}.rok^{-1}$, což je méně v porovnání s ostatní ovocnou biomasou. I když brikety vyrobené z rakytníkového dřeva byly kvalitní z hlediska většiny parametrů, nesplnily mezinárodní normu pro tříděné dřevní brikety, z důvodu nižší hustoty částic a vyššímu obsahu síry a dusíku. Ačkoliv rakytníkové dřevo zlepšilo klíčové palivové parametry kombinovaných briket, jako výhřevnost a obsah popela, mechanické parametry byly většinou zhoršeny.

Klíčová slova: *Hippophae rhamnoides,* výnos biomasy, briketa, energetické využití, normy, technické parametry

Abstract

The energy consumption has been growing during last years and identification of new possible sources could improve energy self sufficiency of many regions. The residual biomass, obtained as a by-product of the agriculure production could provide significant amount of energy for heating or electricity generation. Biomass residues produced in fruit orchards or plantations are one of the potential energy sources, as well as residual straw which is abundant in agriculture. However, its energetic properties are problematic. This study assesses the amount of residual wood produced in Sea buckthorn (*Hippophae rhamnoides*) orchards and its possible use in the form of briquettes for heating. The yield of residual SBT wood was studied under conditions of Czech Republic and briquettes made from this wood waste were evaluated according to international standards for solid biofuels. Furthermore combined briquettes made of mixtures of SBT wood with wheat straw and rape straw were produced, in order to assess the influence of SBT wood on technical properties of these briquettes. The yield of residual wood was measured as 0.93 $t.ha^{-1}.yr^{-1}$ (d.b.) which is lower in comparison to other fruit biomass. Despite the briquettes made of SBT wood were of good quality, they did not meet international standard for graded wood briquettes due to lower particle density and higher content of sulphur and nitrogen. Altough the SBT wood improved crucial fuel parameters of combined briquettes, such as net calorific value and ash contents, the mechanical parameters were mostly worsened.

Key words: Hippophae rhamnoides, biomass yield, briquette, energy utilization, standards, technical parmeters

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LIST OF ABBREVIATIONS

CULS - Czech University of Life Sciences Prague

d.b. - dry basis

EU - European Union

GHG - Greenhouse gas

MC - Moisture content

NCV - Net calorific value

OECD - Organisation for Economic Co-operation and Development

RES - Renewable energy source

SBT - Sea buckthorn

SOC - Soil organic carbon

SOM - Soil organic matter

USA - United States of America

VÚZT - Výzkumný ústav zemědělské techniky

w.b. - wet basis

I. INTRODUCTION

Energy utilization of residual biomass has been growing in recent years and currently plays significant role in many national strategies. Because the fossil fuels produce high amount of emissions which negatively affect atmosphere by accumulation of greenhouse gases, there are global efforts to reduce utilization of these resources. The advantage of biomass is ability to bind back CO_2, released during combustion (Havrland et al., 2011). Moreover, renewability of biomass predestines this energy resource for long-term and sustainable use in comparison with coal, oil or natural gas. Cultivation of energy crops on land, where could be grown food, is often discussed in relations with worldwide food security. Conversely, residues arising as a by-product within agriculture production could provide amount of energy without compete for land. Beside of large amounts of residual straw, is significant amount of biomass generated within fruit production in orchards. As a problematic aspect of biomass utilization is considered its low density and form which is difficult for manipulation, transportation and storage. For lowering costs of transportation and easier manipulation, biomass could be transformed to certain form of solid biofuel, such as briquettes or pellets (Garcia-Maraver et al., 2015). Densification of biomass into solid biofuels improves fuel qualities of material from the viewpoint of transportation, handling and storage. Therefore, is utilization of residual biomass for energy is actual topic, as well as mapping of all available resources.

Sea buckthorn (*Hippophae rhamnoides*) is a thorny shrub or tree grown for berries which contain valuable medicinal substances. Moreover, SBT is used as an erosion control plant, nitrogen fixing plant or as a fodder. In some regions is also used as a fuelwood, due to its greater ability to accumulate biomass in harsh conditions in compare to other plants. In the conditions of Europe is SBT cultivated in large-scale orchards for berries production. Harvest is done by cutting whole branches which are frozen and afterwards are berries shaked down. It is given by absence of abcission layer in the berries which makes their manual picking or shaking directly from trees difficult or impossible (Rongsen, 1992). During the process of harvesting berries in large-scale orchards, is therefore generated amount of residual woody biomass which could be used for energy. The biggest SBT berries producer in Czech Republic uses this wood for heating. However, due to high volume and low density of material is heating and manipulation with biomass problematic and improvement by densification looks promising. Moreover, surpluses of wood could be transformed to the biofuel and serve as a marketable commodity which can earn extra money for farmer.

The biggest SBT producers worldwide are China, Russia, Mongolia or India and other countries in Asia. These countries have often problems with deforestation and erosion, related to the fuelwood collection or excessive utilization of land. In these regions could cultivation of SBT provide fuelwood, as well as berries for food and market or erosion and nitrogen fixing effect on the soil (Bajer, 2014). In the conditions of Czech Republic is cultivated only about 150 hectares and utilization of residual wood has only local character. However, since the majority of production is located in China and in countries named above, the significance of residual wood in these regions could be higher.

SBT is a multipurpose species which improves soil quality through root system, produces berries with high content of medicinal valuable substances, leaves which could be used as a fodder and fuelwood for heating and cooking. As a naturally grown shrub, SBT provides services for rural people in arid conditions of Himalayas, where other plant species are not able to survive (Rongsen, 1992). Since cultivation of SBT begins to expand to other countries, the orchards could provide stable amounts of available biomass for energy use. While berries and soil effect of SBT have been studied widely during last decades, the amount of residual wood within orchard cultivation and its properties have not been studied yet, as well as possible utilization of this wood for production of solid biofuels.

II. LITERATURE REVIEW

2.1. Sea buckthorn (*Hippophae rhamnoides*)

2.1.1. Plant morphology and description

SBT is usually known as a thorny shrub, bearing orange or yellow berries which often consist on the branches throughout the winter and serves as food for birds. Normally reaching 2-4 m height. However, in dependence on species and geographical location this height varies (Li and Schroeder, 1996). According to Bajer (2014) species of *Hippophae tibetana* occurs only in the form of low shrub with height between 10-15 cm, exceptionally in higher form up to 80 cm. On the other hand species *Hippophae rhamnoides* can reach up to 15 m height. These extermely high trees were found in western Europe and on Aland islands, where can SBT reach up to 10 m high with average lenght of life about 30-40 years.

SBT is known mainly for its nutritional and medicinal value. Berries contain different kinds of nutrients and bioactive compounds including vitamins, fatty acids, free amino acids and elemental components (Bal et al., 2011; Suryakumar and Gupta, 2011, Li and Beveridge, 2003). Sea buckthorn is dioecious plant and therefore only female plants fruit berries while male plants produce brown flowers necessary for pollination. Flower buds are formed on new growing shoots and berries are produced on last year wood. The male buds consist of four to six apetalous flowers while the female buds consist of single apetalous flower with one ovary and one ovule (Suryakumar and Gupta, 2011). Pollen is transimitted by air, while insects play only insignificant role because flowers does not contain nectar searched by insects. Flowers of male plants are larger and more obvious in compare with female flowers which are tightly sessile to the shoots and after pollination change to berries (Bajer, 2014). Male flowers and mature berries are shown in the ***Figure 1.***

Young fruits are hard and greenish, while in the time of ripeness are mostly orange and soft. The colour varies according to the species from light yellow to red (Kalia et al., 2011). Due to its ability of bearing fruits over the winter and colour atractiveness, is SBT grown as an ornamental suplement shrub in the gardens or as a live fence. Berries are of round or cylindrical shape and of the length between 4-12 mm, according to species and variety (Bajer, 2014). The size is mostly decribed as a weight of 100 berries and varies significantly according to the species. While 100 berries of the species *H. neurocarpa* weight only between 4-5 grams, plants of species *H. rhamnoides* found on the seashore of Baltic sea and in Siberia produce berries of 60 g/100 berries under natural conditions. However, some Russian cultivars such as „Ažurnaja“ produce large berries of weight up to 121 g/100 berries (Bajer, 2014; Kalia et al., 2011).

One of the specific features of SBT berries is absence of abscission layer which causes problems with harvest and increases costs for production of these berries. Absence of this layer, which is normally present around the stalks of other fruits, makes harvest of these berries difficult because in the time of picking are soft and tightly clustered on branches (Li and Schroeder, 1996). Therefore manual picking causes losses of biologically valuable substances contained in the berries (Chagnon et al., 2009). ***Figure 2*** shows berries which were left in the orchard after harvest and in contrast to leaves are still tightly attached to the plant, even in the winter months.

Figure 1.: Mature berries (left) and male flowers (right)

Figure 2.: Non-harvested berries in December 2014

The leaves are narrow linear or linear-lanceolate with alternate arrangement, however some plants from south-east China have leaves in opposite arrangement. The length varies usually between 20-80 mm and width 2-9 mm (Bajer, 2014; Enescu, 2014). Upper surface is normally darkly or silverly green, while the lower site is covered by grey or rusty scales. From the lower site is also visible protruding midrib and short petiole (Enescu, 2014). The leaves contain nutrients and bioactive substances such as flavonoids, carotenoids, free and esterified sterols, triterpenols, and isoprenols. The leaves are rich source of important antioxidants, such as carotene or vitamin E, contain about 15% of protein. Using of the leaves as a feeding for animals is still practiced, as well as products made from dried leaves such as tea or tea powder (Suryakumar and Gupta, 2011; Li, 2002).

The bark of SBT is usually dark brown and rough, and varies according to the age of plant. Young shoots have a light grey-green colour of bark with brown tone while on the second year wood colour changes to grey or brown (Bajer, 2014). Bark contains valuable Serotonin which affects human emotions, adjusts blood pressure and acts as an aphrodisiac while the lack of this substance causes insomnia.

As a pioneer plant, SBT naturally occupies marginal lands on the river banks, basis of the mountains or coastal dunes which is given by specific root system. Root system consists of the main vertical root which in the first year penetrates soil to the depth about 50 cm and of horizontal roots which grow usually in the second year and the most of its matter is located in the upper soil layer to the depth of 40 cm. Main matter of root system is located in upper layer and this fact has to be taken into account during cultivation. In natural conditions is SBT spread mainly by root suckers, therefore does not occur in areas covered by grasses which have higher competitive ability in the upper soil layer (Bajer, 2014). Due to the specific structure of root system is SBT considered as a valuable agroforestry species often use for mitigation of soil erosion (Enescu, 2014), use in the land reclamation (Zhao et al., 2012) or in other agroforestry practices (Sun et al., 2008).

Ability to fix air nitrogen by root nodules is similar to that in leguminous plants (Li and Schroeder, 1996; Kalia et al., 2011; Enescu, 2014, Issah et al., 2014). Nitrogen fixation is caused by bacteria *Frankia* living on parenchyma of root system which forces plant to create nitrogen fixing nodules (Bajer, 2014). Therefore, could be SBT cultivated in the soils poor of humus, on the spoils left after mining activities or on sandy dunes (Musayev, 2013). Effect of SBT on the soil properties were researched by Zhao et al. (2012) and it was found that SBT significantly improve soil field capacity, aggregation, microbiological composition and total microorganisms.

2.1.2. History of Sea buckthorn

The first mentions about Sea buckthorn has known since the ancient times. In ancient Greece were leaves and young branches used as a fodder suplement for horses which caused rapid weight gain and also healthier and shinnier coat. (Li and Beveridge, 2003; Musayev, 2013; Rongsen 1992). Bajer (2014) also mentions greece legend about winged horse Pegasus which was fed by SBT fruits and leaves. These berries and leaves gave him supposedly the power for flying. The generic name *Hippophae* were probably derived in time of Alexander the Great. Soldiers and horses used SBT for regenaration and as a side effect horses get shinny and healthy coat. According to this ability of SBT were derived the generic name *Hippophae* which means shining horse. One mongolian legend says that in 13th century conqueror Genghis Khan used SBT fruits and leaves for soldiers and horses which gave them power and endurance for conquering the world (Bajer, 2014).

SBT have been used for centuries in Tibet, China, Mongolia, Siberia but also in Greece and in Roman Empire. However the first written mention about its medicinal value was recorded in the 8 century in the Tibetian medical classic „rGyud Bzi“. In the area of China were SBT used only in the mountain regions, therefore could be used for centuries without any mentions (Bajer,2014; Li and Beveridge, 2003).

In the past times were SBT probably utilized extensively, only as a naturally growing shrub. This was changed in 20th century, when the biggest attention to this plant was given in Russia because it is the only species able to bear the fruits and sustain in harsh climatic conditions of Siberia. In the beginning of 20th century were also determined chemical properties of fruits which many times surpassed vitamin and mineral contents in other fruits (Bajer, 2014). The first factory for processing SBT fruits was established in 1949 in the Russian city Bijsk and produced oil and food suplements which were also used by cosmonauts (Li and Beveridge, 2003). After the second world war started intensive research on SBT production and utillization in China. Altough they had experiences with this plant for centuries the first plantations were established in 1980's. Except fruit production, is SBT used in China as an erosion control medium for fragile lands. According to Rongsen (1992) were betwen 1986-1989 in China, Loess Plateau established 213,000 ha of SBT forests which significantly decreased the soil losses in the region. Since 1982 have been planted in China about 500,000 ha and established more 150 factories for processing SBT fruits.

In the last decades SBT expanded to many other countries in Europe, United States and Canada, but also to Bolivia where was planted in 2003 first 50 ha of SBT. According to Bajer (2014) is in Czech Republic currently cultivated about 150 ha of plantations and about 100 ha are cultivated by one producer (Košek, 2014).

2.1.3. Natural habitat and distribution

SBT occupies various types of ecosystems, including steep slopes of high mountains, flooded sandy banks of rivers or ocean coastal dunes with high occurence of strong winds. As a western boarder of the natural occurence is considered northern Europe, where SBT occupy mainly river banks and coastal dunes along Baltic Sea in Finland, German and Poland, along the Gulf of Bothnia in Sweden or in coastal areas in Great Britain and Ireland (Li, 2002; Li and Beveridge, 2003; Ranwell, 1972). In the continental Europe is spread on the hillsides and along mountain rivers in Spain, south of France, Switzerland, Italy, Austria, Hungary, Romania and coastal areas of Bulgary (Bajer, 2014).

SBT is further widespread to the East and occupy large areas along the Black Sea in Turkey, Georgia, Armenia and Azerbaijan (Musayev, 2013). In the Central Asia region creates SBT unpenetrable thickets in the valleys of rivers and coastals in the mountain systems of Tian Shan and Pamir where can be found up to altitude of 3,800 m. In Russia can be SBT found in many different regions. Large areas of origin shrublands are widespread along the influx of Danube in Odessa region, in Siberia covers areas in Altai region along the valleys of steppe rivers. However, the biggest area of SBT in Russia is located in the area of the city Bijsk. These shrublands occupy mainly lowlands along the river Katuna and because of their large berries, were these plants used for further breeding (Bajer,2014; Li and Beveridge, 2003).

As an eastern border of the area of distribution is considered northern Mongolia and China, where is located most of natural habitats in the world. According to Bajer (2014) is in China located about 90 % of total origin areas of SBT in the world. In Mongolia is SBT found in the north and north-west where is widespread mainly in the valleys of rivers in Altai mountains and south boarder is created by the river Zavchan. In the area of Gobi dessert grows SBT only sporadically and is found again in eastern provinces of China. In densely populated areas sustains in the valleys of mountain rivers mostly in gravel depositions, inappropriate for crop cultivation (Hlava a Valíček, 1989). Natural vegetation in China is found in provinces Sechuan, Yunan and in alpine areas of Tibet. The highest trees were found in province Sechuan where prevails subtropical climate and plants can reach about 15 m with a trunk diameter more than 1 m (Bajer, 2014). Natural forests of SBT are found also in other countries throughout the Himalayan region including India, Nepal, Bhutan, northern parts of Afghanistan and Pakistan (Rongsen, 1992; Li and Beveridge, 2003).

2.1.4. Environmental requirements and cultivation

SBT is a hardy plant which grows and bears fruits in the conditions where other fruit species failed. For its frost and saline tolerance is often cultivated on the marginal soils where other plants show lower yields or total inability to grow (Bajer, 2014). According to Hlava and Vaníček (1989) is SBT root system able to withstand temperatures about –22°C and above ground biomass witstand even -50°C. Similar data show also other authors (Rongsen, 1992; Li and Schroeder, 1996; Enescu, 2014; Li and Beveridge, 2003). SBT has been used for the centuries only as a wild growing shrub in mountainous areas. In the beginning of 20th century started in Russia intensive selection research on its cultivation in the orchard or plantation conditions (Bajer, 2014). Altough is SBT very tolerant to wide range of climatic and soil conditions, for intensive cultivation which produce good yields in the sustainable way, should be met some specific requirements.

SBT prefers to grow in low humid, alluvial gravel, wet landslips and riverside soils (Enescu, 2014). The fact that in natural conditions grows mainly in the coastal and riverside banks shows that prefers light to medium sandy loam soils or silts which often occur in these areas (Bajer, 2014; Li and Beveridge, 2003). These types of soils provide good access of air to the roots and good drainage abillities because SBT does not withstand long-term waterlogging. In the soils with poor porosity, execess of water and lack of air, plants suffers and often died (Rongsen, 1992). In China were found plants in the soils with different pH ranging between 5.5 to 8.3 which shows that acidity or alkalinity are not limiting factors (Rongsen, 1992). According to Li and Beveridge (2003) SBT lives in symbiosis with soil bacteria *Actinomycetales* which have low tolerance for soil acidity and prefer soil pH between 5.4 to 7. Soil pH is important especially in the phase of orchard establishment. When young seedlings are planted, soil pH should be between 6-7 (Rongsen, 1992; Li and Beveridge, 2003; Bajer 2014).

SBT prefers sunny sides of mountains or river banks in natural conditions, therefore it is considered as a sun loving crop (Hlava and Valíček, 1989). According to Li and Beveridge (2003) are yields significantly affected by the orientation of the rows to the sunlight and for maximizing the sun light penetration is recommended north-south orientation of the rows. The most of the natural vegetation is found in the areas with annual rainfall between 400 to 600 mm, however for the economic purpose is the most suitable annual precipitation about 500 to 700 mm. The area for planting SBT should be selected according to these requirements which support establishment of young plants and their further development (Rongsen, 1992).

Orchard cultivation requires specific spacing of male and female plants which should be placed in order to ensure proper distribution of pollen. According to Bajer (2014) is for large-scale cultivation in orchards recommended spacing 4-5 × 1-2 m in dependence on used equipment for harvesting and other practices. When spacing 5 × 1 m is used, can be planted 2000 plants per hectare and it is reccomended that about 6 to 8 % of them should be male plants (Li and Beveridge, 2003). For good pollination, the distance should not exceed 16 m between male and female plants.

For establishment of new plantations are used cuttings, seedlings or transplanted root suckers from existing orchards. From the agrotechnological point of view is using of seedlings unsuitable because of sex uncertainity during first 3 years of growth. Therefore is prefered to use cuttings or root suckers to assure certain distribution of male and female plants within orchard (Bajer, 2014). Rongsen (1992) reported effective use of utilization of seedlings in Loess Plateau, China. Deforested areas in this region were air-seeded by seeds of SBT, to decrease erosion and enhance soil stability. This method was used in 1977-1979 when was seeded 1,240 ha of deforested land in semi-arid region of Loess Plateau and after

4 years in 1983 was observed that most of the seeded area was covered by SBT forest (Rongsen, 1992). In the production orchards is necessary to know sex of plants, and therefore is establishment of orchards done mainly by hardwood or softwood cuttings which produce genetically uniform plants of known sex. Another option of propagation is transplantation of root suckers which are created during the early years after planting (Li and Beveridge, 2003; Bajer, 2014; Košek, 2015).

Except pruning and removing of old and redundant branches is in productive orchards common to apply fertillizers. According to Bajer (2014) SBT shows good yields in the soils rich in humus and with higher content of mineral compounds, especially phosporus and potassium. Lack of nitrogen in the soil is supported by nitrogen fixing, filamentous bacteria *Frankia* which live in symbiosis with actinorhizal plants, such as genus *Hippophae* (Rongsen, 1992; Li and Beveridge, 2003; Enescu, 2014; Hlava and Valíček 1989). Bajer (2014) states that is important to control content of phosphorus in the soil which supports reproduction and growth of nitrogen fixing microorganisms. Fertillizers are applied before orchard establishment and on the annual basis for the first three years after planting. Before planting should be incorporated to the soil 200-250 $kg.ha^{-1}$ of phosphate and 150-180 $kg.ha^{-1}$ of potassium fertilizer. For young outplantings is recommended spring fertillizing of 80-100 $kg.ha^{-1}$ of phosphate, 60-90 $kg.ha^{-1}$ of potassic and 40-60 $kg.ha^{-1}$ of nitrogen fertillizers (Bajer, 2014). Li and Beveridge (2003) present results of 5 year research in Siberia, that showed increase of yield by 23 % caused by applying of N, P_2O_5 and K_2O in the amount 60:60:60 $kg.ha^{-1}.yr^{-1}$.

2.1.5. Harvesting of Sea buckthorn

The first harvest is usually done in 3-4 years after establishment and it is considered as the most time and money consuming activity in SBT cultivation (Hlava and Valíček, 1989; Li and Beveridge, 2003). Due to absence of abcission layer between peduncle of fruit and branches, are fruits often held over the winter and is difficult to harvest them manually in compare to other fruits (Bajer, 2014). According to Li and Beveridge (2003) are harvesting difficulties considered as a main constrain for cultivation of SBT in developed countries, where the labor costs are considerably higher than in less developed countries. In Saskatchewan region, Canada present labor costs for manual picking of berries in 4 ha orchard 58 % of total cummulative production costs over 10 years. Therefore, are nowadays evolved different types of mechanical harvesters and equipment to make this operation faster and less economic demanding.

The time of harvest plays an important role because of changes in chemical components and mechanical properties of fruits which stay on the branches and ripe over their optimal ripeness (Bajer, 2014). Viškelis et al. (2008) observed decreasing tendencies of vitamin C content and increasing content of carotenoids during fruit rippening. It was also found that while mechanical strength of fruit decreased over time of rippening, the force needed for detachment increased over this time. From the consuming point of view are overripen fruit not suitable for consumption, especially in the case when are left frozen and refrozen repeatedly. Due to this process, oils contained in the pulp are getting rancid and cause unpleasant taste of berries (Bajer, 2014).

Manual picking of berries still occurs in less developed countries and in small-scale productions for which would be mechanical harvesting economically unsuitable. According to Viškelis et al. (2008) can average worker collect 5-6 kg per day of berries by hand. With the maximum possible orchard yield 10 $t.ha^{-1}$ (Li and Schroeder, 1996) would be one hectare of orchard harvested by 100 workers for 16-20 days which is economically unviable in our conditions. Viškelis et al. (2008) observed lower yields of berries harvested manually from four different cultivars in compare to cutting whole branches and shaking berries after freezing. Average yield of berries harvested manually was 8.8 $t.ha^{-1}$ while cutting branches yield 9.6 $t.ha^{-1}$ on average. The lower yield is imputed to the fact, that manually gathered fruits are often broke and the juice that flows out causes losses to the mass. Bajer (2014) also mentions the thorniness, as a limiting factor for manual picking which is often replaced by cutting the whole branches and removing of berries afterwards.

Berries can be harvested by mechanical or manual shaking directly from the plant (Li and Beveridge, 2003; Bajer 2014; Mann et al., 2001). Manual shaking is still practiced, mainly in Himalayan region where the berries are shaken by hitting the branches with a sticks and catched in the sheets spread under the canopies. Mechanical shaking harvesters and equipment are still under research, mainly in Canada. Mann et al. (2001) tested harvest efficiency of berry shaker by measuring percentage of removed berries from the branches. In the time of full ripeness in September was measured that berry shaker can remove only about 50 % of berries, even if the higher vibrating frequencies and amplitudes were used. Attempt was repeated again in November when the branches were subjected to overnight frosts of approximately -8°C, in Saskatchewan, Canada. In this time were obtained the best results, when 99% of berries were easily shaken down which is atributted to lower temperatures in November. Bajer (2014) mentions succesful testing of berry shaker in Romania which was able to harvest 29-30 plants per hour and harvested 800-900 kg of berries in 8 hours. As a main advantage of manual or berry shaking harvesting is considered that during these methods are not removed annual shoots which will bear fruits next year (Li and Schroeder, 1996).

In the larger orchards is today practiced mainly harvesting by cutting whole fruiting branches, their freezing in the freezing plant and consecutive shaking berries. This could be done by specially designed harvesters or manually with hand tools like saws or pruners. According to Bajer (2014) is for this types of harvesting necessary to select well regenerating and resistant varieties which tolerate deeper cut. As a main disadvantage of this method is mentioned removing of annual shoots which would bear fruits next year and therefore can be harvest obtained once in 2 years which is economically unsustainable in conditions of United States (Li and Beveridge, 2003). However, according to personal observation and discussion with largest Czech producer Košek (2014) are these practices different in some cases and under conditions of Czech Republic sustainable. Košek (2014) claims that in some orchards are during harvest carefully selected and harvested only fully fruiting branches, while less productive branches are left with annual shoots to fruit next year. This method of harvest can be practiced only by using hand tools for removing branches because using of special harvesters does not assess more or less fruiting branches. Periodical pruning is necessary in orchard lay-out to provide enough of sun light. Furthermore, is harvesting of berries by cut-and-freeze method advantageous because harvesting by picking or shaking requires additional work for pruning which is in the case of cut-and-freeze method donein one operation (Bajer, 2014). This method generates a lot of woody residues which can be used as a fuel for heating or as a material for mulching. Mechanical harvesters were developed in Sweden, Germany and Russia but their utillization is only rare, mainly due to low efficiency, excessive damages on plants and inability to control which branch will be cut (Li and Beveridge, 2003). One worker can harvest branches with 100-150 kg of berries in 8 hours. In compare to 5-6 kg per day by manual picking is obvious that manual picking can be done only for own consumption or in the areas where the worker wages are low. Another advantage of cutting whole branches is that berries harvested this way can be stored for 14 days without losses on the berries (Bajer, 2014).

Other ways of harvesting technologies are under development or were rejected after testing. Varlamov and Gabuniva (1990) evolved harvesting device working on the principle of picking berries from the shrub by suction air stream. This device shows efficiency 99% of total picked berries from the plant and productivity increased 4.6 times when compared to manual harvesting. Patočka et al. (1996) developed manual cutting harvester which works on the principle of comb with knife and harvest berries with peduncles by moving this device along the fruiting branches. Tests showed that by this device can be harvested over 5 kg of berries per hour but it also showed relatively high percentage of damaged berries which varied between 13.2 % and 34.1 %. Effects of hormonal treatment on reducing detachment forces of berries were also researched and showed promissing results. Li and Beveridge (2003) reported that by application of ethylen solution 7 days before harvest was reduced detachment force by 30 %. This fact can be helpfull especially for shaking harvesters which were able to remove only 50 % of berries in their full biological ripeness (Mann et al., 2001).

2.1.6. Utilization of SBT

SBT is considered as a multipurpose plant due to its variability of utilization along the World (Rongsen,1992). SBT is valued mainly for its medicinal and nutritional value of berries (Mann et al., 2001; Bawa et al., 2002; Li and Beveridge, 2003; Bajer, 2014; Zadernowski et al., 2003; Musayev, 2013). However, valuable medicinal substances have been found also in other parts of plant. Mainly leaves and bark, but also young shoots can be used for extraction of valuable substances. Furthermore, is SBT considered as an erosion control plant which can be planted on marginal lands and due to developed root system significantly decreases erosion rates. Ability to fix air nitrogen by symbiotic mycorhizal bacteria in root system determinates this plant for use on land recultivations and on depleted soils (Bajer, 2014). SBT is also considered as an important source of firewood which is used as a source of energy in deforested rural areas of Himalayas (Rongsen, 1992).

Medicinal and nutraceutical utilization

Fruits of SBT are valuable source of carbohydrates, protein, organic acids, amino acids and vitamins. Their content in berries vary according to fruit maturity (Viškelis et al., 2008), fruit size, species or geographic location (Rongsen,1992). Pulp of berries contains usually

3-5 % of oil, whereas the oil content of the seeds is 12-13 % (Zadernowski et al., 2002). Oil is valued for its properties and wide posibilities of utilization. Fatty acids in this oil are created from 80 % by unsaturated acid with high content of linoleic and linolenic acid which are considered as an indicators of good oil quality. Furthermore, the content of β-carotene and Vitamin E is higher than those of other oils and therefore is considered as a valuable medical oil (Rongsen, 1992). All parts of SBT are considered to be a good source of large number of bioactive substances like vitamins (A, C, E, K, riboflavin, folic acid), carotenoids, phytosterols, organic acids (malic acid, oxalic acid), polyunsaturated fatty acids and some essential amino acids (Suryakumar and Gupta, 2011). For centuries has been used in oriental systems of medicine for treatment of asthma, skin diseases, gastric ulcers and lung disorders. Leaves from the male plants are used for tea preparation because of their Vitamin C content and other substances (Li and McLoughlin, 1997). Generally, the content of Vitamin C is the most important feature of SBT and in compare to other fruits and vegetables is higher, as shown in the ***Table 1*** (Rongsen, 1992).

Table 1.: Vitamin C content in different fruits and vegetables

Species	mg/100g fruit	Source
SBT *(Hippophae rhamnoides)*	27.8-310	Zeb (2004)
SBT *(Hippophae sinensis)*	200-2500	Zeb (2004)
Cili *(Rosa roxburghi)*	1000-3000	Rongsen (1992)
Kiwi fruit *(Actinidia sinensis)*	100-470	Rongsen (1992)
Hawthorn	100-150	Rongsen (1992)
Orange	50	Rongsen (1992)
Tomato	11.8	Rongsen (1992)
Carrot	8	Rongsen (1992)

Utilization of medical substances found in SBT was studied by many researchers (Suryakumar and Gupta, 2011; Chen et al., 2013; Zadernowski et al., 2002; Bal et al., 2011; Ito et al., 2014). High content of flavonoids in fruits and leaves is valued in treatment of cardiovascular disorders. As reported in Chen et al. (2013) the total flavonoids from aqueous ethanol extract of SBT berries have been clinically used in China since 1980 for treatment of cardiovascular disorders. The substances contained in oil are known for promoting skin and mucosa epithelization. Therefore, is SBT oil used in healing burn wounds. SBT seed oil is becoming more attractive and commonly used in the area of skin care because of its abundant omega-7 unsaturated fatty acid content. Ito et al. (2014)

studied healling efficacy of SBT seed oil on burn wounds of ovines and found that the epithelization time of the treated ovines site was significantly shorter than that of the untreated site. Other substances from SBT are used for treatment and prevention of different problems such as treatment of radiation damage, burns, oral inflammation, and gastric ulcers. Other positive health effects include reduction in plasma cholesterol level, inhibition of platelet aggregation, and regulation of immune function (Zadernowski et al., 2002). Production of food products is still in beginning in the European conditions. Products, such as jams, juices or instant drinks produced by Ekoplanet Co. are shown in the ***Figure 3***.

Figure 3.: SBT products made by Ekoplant Co.

Erosion control and soil improvement utilization

SBT is used as a soil improving and erosion control plant in many countries. Due to its developed root system is SBT planted in restorations of devastated soils after coal minning activities, in eroded lands with low humus content and as a fixing medium on steep slopes (Rongsen, 1992). Due to its ability of vegetative reproduction by root suckers often creates homogenous vegetation cover which effectively decreases erosion rate (Bajer, 2014). Another specific feature is its ability to fix air nitrogen by root nodules. Thanks to mycorhizal bacteria of genus *Frankia* is plant forced to produce these nodules and due to this nodules is 1 ha able to fix 180 kg of nitrogen per year (Rongsen, 1992).

Rongsen (1992) reported study from China where 7 year old SBT forest were able to reduce water and sediment run-off by 99 % and 96.6 %, respectively in compare to deforested areas in this region. Effect of nitrogen and organic matter content in the soil is mostly visible in the top soil layers. It was found that in compare to natural waste mountain slopes in Loess Plateau, China, SBT forest increased nitrogen and organic matter content in the upper soil layer by 1.7 and 2.1 times, respectively (Rongsen, 1992). Zhang and Chen (2007) observed effect of SBT pure and mixed forests in Eastern Loess Plateau on species diversity, soil physical and nutrient conditions. It was found that SBT has positive effect on species diversity, soil physical and nutrient conditions while this effect was more obvious in mixed forests than in pure forests. Best results were achieved in the combination of *Hippophae rhamnoides* (SBT) with *Pinus tabulaeformis* and was concluded that plantations mixed with *H. rhamnoides* are effective way to accelerate forest growth and environmental improvement Zhang and Cheng (2007). In Canada was SBT adopted as a shrub species used in buffer strips along the river riparians as an erosion control plant (Li and Beveridge, 2003).

Wood utilization

Except medical, nutritional and soil utilization, is SBT used as a source of firewood, mainly in rural mountainous and deforested areas in Asia. This perennial woody shrub, growing vigorously even in harsh conditions, produce higher volume of biomass than other species (Rongsen, 1992). Using of SBT wood as a fuel was described by Gamble (1902): „The wood is used for fuel and charcoal, and the dry branches for hedges. It is very valuable source of fuel in dry and treeless tracts of the Inner Himalaya." Especially rural Himalayan areas suffered during winter by lack of fuelwood due to sparse of woody vegetation in cold mountain desserts (Stobdan et al., 2013). Christensen et al. (2009) reported that SBT is one of the important trees in rural Nepal used as a source of fuelwood. Dry SBT wood has calorific value 4,785 cal.kg $^{-1}$equal to 20 MJ.kg^{-1} which is higher than other woody biomass (Rongsen, 1992). The shrub is fast growing which allows stumping every 3-5 years. By ability to tolerate repeated cuttings can this practice reduce the harvesting pressure on other native woody plant species such as poplar, willow and juniper. According to Stobdan et al. (2013) can six-year old plantation produce 18 tons of firewood which is equal to 12.6 tons of standard coal.

In conditions of Loess plateau, China, showed SBT greater results of biomass accumulation than other shrub species such as *Caragana korshinskii*, *Rosa xanthina* or *Vilex chinensis*. 15-year old SBT can accumulate 1.98 t.ha^{-1} of fresh biomass in compare to 1.39 t.ha^{-1} of *Caragana korshinskii* or 1.78 t.ha^{-1} of *Rosa xanthina*, of the same age (Rongsen ,1992). In natural conditions has SBT strong ability to sprout from its roots and forms dense woods, which accumulate more biomass than other woody species. Rongsen (1992) reported high economic importance of SBT in poor rural areas of China with lack of firewood and fodder for cattle where can one hectare of SBT produce 4.5 $t.yr^{-1}$ of dried fuelwood and about 1.5 $t.yr^{-1}$ of leaves used as a fodder.

In intensively cultivated orchards is woody biomass often produced as a residual material during harvest. In the process of harvest are thewhole fruiting branches cutted and after artificial freezing are berries shaken. This process leaves a significant amount of woody biomass which can be used for heating or other purposes. Amount of the biomass produced during harvest is difficult to estimate due to large variability in harvesting intensity and practice. ***Figure 4*** shows large amount of woody and leave biomass produced during harvest in orchards of the company Ekoplanet Co., Ohrazenice. Produced biomass in the form of wood chips is used for heating in processing factory and farmers household. The volume of residual biomass in the form of wood chips is large and can not be properly stored due to lack of indoor storage space. Furthermore, is handling of wood chips quiet complicated in compare to woodlogs, pellets or briquettes. Due to innapropriate storage is significant amount of wood lost due to rotting and moulding of undried biomass under natural conditions. This situation could be improved by transforming of biomass into densified form of biofuel which could be stored in smaller space and also handling and heating would be easier in compare to wood chips.

Figure 4.: Harvest residues from Sea buckthorn orchards

2.2. Biomass for energy use

2.2.1. Introduction to biomass energy

Using of biomass as a fuel is known since the beginning of humakind and has been used as a main source of energy for thousands of years. Despite of discovering oil, natural gas or using of nuclear energy in 20th century, is biomass still considered as one of the main energy sources contributing to total energy supply by about 10-14 % (Koçar and Civaş, 2013; McKendry, 2002a; Purohit et al., 2006; Chen et al., 2009). As a common biomass resources can be considered firewood, crop residues, animal manure, energy plants and municipal solid waste (Liu et al., 2008). Level of contribution of biomass to total used energy varies significantly according to region. According to McKendry (2002a) was in 2010 produced 47.8 % of primary energy in Africa produced from biomass resources while in OECD countries only 4.5 %.

Biomass can be transformed to energy by several ways according to requirements and use of produced fuel. Generally, there are two types of biomass conversion to energy: thermochemical (combustion, pyrolisis, gasification) and biochemical (fermentation, anaerobic digestion) (McKendry, 2002a). In developed countries, projects such as biomass electricity generating or biomass liquid fuels production, have been already ranked in national energy strategies. Conversely, in the most of developing countries is practiced combustion of firewood and crop residues, as a main source of energy (Liu et al., 2008). Combustible renewables and wastes plays important role as an energy source in developing countries and regions due to relatively simple way of transformation in compare to other technologies which requires higher investments and operational costs. Furthermore, in compare to the renewable energy sources, such as wind and solar power, biomass has advantage that contained energy can be easily stored and used in the time of need. Storage of electricity produced by wind or photovoltaics is difficult and often unfeasible.

Due to population pressure and growing demand for energy resources in Africa, are often deforestated wide areas of local forests. It is estimated that about 70 % of deforestation in 2010 was caused due to fuelwood demand and this rate should grow up to 83% in 2030 (Subedi et al., 2014). Hosonuma et al. (2012) studied deforestation drivers in different continents: Africa, Asia and Latin America. He estimated that while for Asia and Latin America is timber extraction and logging main driving force (> 70 %), fuelwood collection and charcoal production is the main degradation driver in Africa (48 %). African forests degradation is more related to small-scale subsistence activities in order to assure energy for cooking and heating. Conversely, in Asia and Latin America is degradation caused by large-scale timber extraction and logging. India produces a huge quantity of agricultural residues and a major part is consumed in traditional use (fodder, construction material, heating, cooking) (Tripathi et al., 1998). Decreasing availability of fuelwood in India has necessitated that efforts be made towards efficient utilization of agricultural residues instead of exploiting forests (Purohit et al., 2006).

Nowadays is biomass considered as an important source of renewable energy which is in the principle CO_2 neutral and could partially substitute fossil fuels in heat and electricity generation. Burning of biomass contributes no new carbon dioxide (CO_2) to the atmosphere, because replanting of harvested biomass ensures that CO_2 will be absorbed and returned by new plants. Therefore, use of biomass does not contributes to a build up of CO_2 in the atmosphere. (Gustavsson et al., 1995; McKendry, 2002a; Weger, 2009; Ngusale et al., 2014; Wang et al., 2014; Havrland et al., 2011).

Furthermore, burning of biomass instead of fossil fuels reduce sulphur dioxide (SO_2) emissions which are produced mainly by burning of coal and oil. Through chemical transformation into sulfate aerosols, SO_2 influence global and regional climate conditions and atmospheric chemistry. Major of SO_2 emissions are produced by combustion of fossil fuel at power plants (73 %) and other industrial facilities (20 %), while the rest (7 %) are of natural origin (Ray and Kim, 2014). This study is focused on utillization of harvest residues for energy by combustion conversion. Therefore, are further chapters aimed on these topics.

2.2.2. Biomass energy trends and strategies

Europe

As a fossil fuels significantly contribute to global climate changes and for human use are limited resource of energy, there is worldwide endeavor to use renewable and more environmental friendly resources**.** In 2001 European Union (EU) adopted Directive (2011/77/EC) promoting electricity production from renewable energy sources. This policy was confirmed in 2008 and includes the Climate and Energy Package, extending the EU′s climate policy beyond 2012. The package includes three targets to be reached by 2020: a 20 % reduction in greenhouse gas (GHG) emissions from the 1990 level, 20 % of renewable resources in energy consumption and 20 % increasement in energy efficiency

(Bertrand et al., 2014). Increasing utilization of renewable energy resources is a part of energy strategies all over the world, causing higher demand of biomass. In the Europe is biomass acknowledged as a main renewable energy source (RES) for achieving EU targets (Welfle et al., 2014).

USA

The United States of America (USA) are one of the countries which try to stimulate the use of renewable energy through the legislations. There have been several legislations during the last years which stimulate the expansion of renewable energy in the USA by different initiatives, such as tax credits or financial incentives. Named can be Energy Policy Acts which passed in 2002 and 2005 or Federal Energy Independence and Security Act enacted in 2007. In 2011 the USA president Barack Obama proposed that by 2035 will be 80 % of electricity in the US produced from clean energy sources and from the state New Mexico is expected that by 2020 will be 20 % of total consumed energy will come from renewables (Lean and Smyth, 2013). Furthemore, the USA hope for substitution of fossil fuels in transportation sector with a target to use 20 % of energy used in transportation from renewable resources, mainly by ethanol production. The trends of substituting of environmentally harmful fuels by those fossil is currently obvious in industry sector, where consumed energy produced by biomass exceed those produced by coal (Jones, 2014)

China

China is currently the biggest energy consumer in the world followed by US and EU (CIA, 2015). China has great potential for production of energy by agriculture residual biomass which is available in the amount about 820 million tons each year (Zhang et al., 2014). According to the latest energy plan „The 12th Five Year Plan for Renewable Energy Development" should electricity generated by biomass reached 13 GW by 2015 and by 2020 should be this number doubled, and biomass will generate 4 % of total consumed energy (Xingang et al., 2013). To achieve these targets chinese governmental agencies developed policies and regulations, such as Interim Measures On Renewable Power Surcharge Collection and Allocation or Temporary Measures for Management of Subsidy Fund of Utilizing Straw Energy Resources. Utillization of cereal straw for direct combustion promises large potential for energy production which is not fully utilized yet. According to Wang et el. (2014) there are still many limiting factors in its using, such as the outdated generation technology or high cost of straw collection, storage, and transportation. The highest potential for energy use is in residual straw biomass from maize, rice and winter wheat cultivation which together created majority of the potential biomass for energy use in 2009 (Jiang et al., 2012).

2.2.3 Energy crops issues

Cultivation of energy crops on agriculture land open discussion about its rightness in the context of food security in many countries. Growing of energy crops instead of food crops partially impacts prices of food in EU due to necessity of importing more food (Wijnen et al., 2015). Furthermore, some studies indicate that energy output of corn production for bioethnol in the US is lower than all energy inputs, and through transforming of meadows and other non-agricultural systems to crop lands decrease biodiversity in the area (Cobuloglu and Büyüktahtakın, 2015).

Due to ecological and energetical reasons have been many countries engaged to increase participation of renewable energy sources in total energy consumption. Growing demand of all biomass resources is consequence of governmental policies and subsidies in different countries (Welfle et al., 2014). These trends are visible on expanding areas of grown energy crops which are in Europe used mainly for biodiesel production. In 2005 were energy crops cultivated on 3.5 million ha, while in 2008 this area accounted about 5.5 million hectares in the EU-27 countries. On the most of this land (82 %) was grown rapeseed for biodiesel production and starch and sugar crops (11 %) for ethanol production. Biodiesel is used mostly in transport sector and therefore is expected widespreading of these areas in order to meet EU 10 % target for biofuel use in the transport sector by 2020. For achieving this target is estimated that approximately 21 million hectares of arable land would be needed within EU (Bunzel et al., 2014).

Heďenec et al. (2014) investigated allelopathic effects of leachates isolated from biofuel crops (*R. tianschanicus* x *R. patientia*, *M. sinensis*) and cultural meadow species (*Poa pratensis, Poa annua, Trifolium repens* and *Plantago major*) on seed germination of mustard (*Sinapis arvensis*) and wheat (*Triticum aestivum*) cultivated on sand and soil substrate. Results showed that tested biofuel crops had a significant allelopathic effect on wheat and mustard seeds. This was in contrast with leachate extracted from meadow which showed no allelopatic effect on both substrates (sand and soil) as well as leachate of distilled water for control.

Wijnen et al. (2015) reported possibility of eutrophication of waters in European coastal areas due to leakage of mineral fertillizers used in biofuels production between 2000 and 2050. As an energy crop is in EU cultivated mainly rapeseed and sunflower for porduction of biodiesel. Within energy crops cultivation is common application of mineral fertillizers, mainly nitrogen (N) and phosporus (P). Due to changing of land use systems in order to grow energy crops is likely that eutrophication of coastal water in Europe will encrease and affect flora and fauna living in these waters, mainly in Mediterranean Sea and Black Sea.

As an advantage of biofuels is presented their relatively small contribution to GHG emissions, due to ability of plants to bound CO_2 from the atmosphere. (Gustavsson et al., 1995; McKendry, 2002a; Weger, 2009; Ngusale et al., 2014; Wang et al., 2014; Havrland et al., 2011). However, intensive cultivation of first generation energy crops requires same amount of fertillizers as it would be used for food crops. Agriculture is one of the main contributors of N_2O emissions which are emitted in different intensities according to practiced crop management. According to Del Grosso et al. (2014) released emissions vary significantly and depend on management and type of crops. He observed that highest N_2O emission per one ton of produced biomass are released during cultivation of oil, sugar and starch crops, such as rapeseed, oil palm, soy bean, wheat and maize while lignocellulostic biomass from second generation biofuels showed lower N_2O emissions. From the ***Table 2*** is obvious that lower emissions were emitted from perennial C4 plants, woody plantations and sugar beet and were related to the amount of used fertilizers.

Table 2.: Specific nitrogen fertillizer rates and N_2O emission intensity for different biofuel feedstocks. N_2O emissions due to land use change are only included for palm

Region	Crop	N fertillizer ($kg.ha^{-1}.yr^{-1}$)	N_2O emissions per ton of harvested biomass ($g.ton\ C^{-1}$)
US	Maize	150	250-550
US	Soy	15	300-1100
US	Switchgrass	75	80-160
US	Pine	10	50-120
US	Miscanthus	50	12-35
Brazil	Sugarcane	67	10-50
Brazil	Soy	0	400-1400
Europe	Rapeseed	125	700-4200
Europe	Soy	0	300-1100
Europe	Wheat	185	250-600
Europe	Sugar beet	120	100-150

Europe	Miscanthus	40	20-100
Europe	SRC willow	79	20-100
SE Asia	Oil palm	98	2380-2400

Source: Del Grosso et al. (2014)

2.3. Residual biomass for energy use

Residual biomass is produced along the whole spectrum of human activities, such as agriculture, forestry or food and processing industry According to Welfle et al. (2014) are biomass residue resources considered as the least susceptible to external influence, and therefore represents large potential for bioenergy sector which will increase in near future. Due to population growth will be necessary to produce more food and because land is limited resource, endless expansion of energy crops is not expected. López-Bellido et al. (2014) claims that the main limiting factor for development of biofuels will be land availability due to competition between food crops and energy crops. Utilization of crop residues has advantage of minimizing the impacts of land use changes since no additional agricultural land is used for production in compare to energy crops cultivation (Nquyen et al., 2013).

Wastes and residues can be used in energy transformation by several ways. Factors that influence the choice of conversion process are: the type and quantity of biomass feedstock; the desired form of the energy, i.e. end-use requirements; environmental standards; economic conditions or specific factors of project (McKendry, 2002b). However, the most common type of transformation is still combustion, due to its simplicity and financial modesty in compare to other forms of conversion. Furthermore, plant residues can be combusted together with coal in current coal plants and achieve high conversion efficiency. Co-combustion of coal and biomass as a supplementary fuel is a viable technological option for reducing the harmful emissions (Sahu et al., 2014).

Amount of usable biomass varies according to region, crop species, climatic and soil conditions or available technology. The most abundant biomass source within residues represent agricultural crop residues and forest residues. However, many studies estimate and evaluate potential yields of agriculture crop residues in different regions (Liu et al., 2008; Monforti et al., 2015; Fischer et al., 2010; Panoutsou et al., 2009), there are still uncertainities about its use in context of effects on environment. According to Werther et al. (2000) as a problematic aspects of utilization of biomass residues can be considered:

moisture content, bulk density, ash content, volatile matter or pollutant emissions. These aspects are often limiting factors in utilization of residual biomass due to complications arising during storage, transportation or combustion. Furthermore, the most abundant residue source (cereal straw) is also used by different ways, such as maintanance of soil properties, fodder, bedding for animals or industry material (Scarlat et al., 2010; Liu et al., 2008). This study discuss potential of residual biomass after SBT harvest for energy generation in the form of solid biofuels designed for combustion. Therefore, are further chapters focused on crop residual biomass.

2.3.1. Residual biomass potential

Heinimö and Junginger (2009) estimate that in 2005 was globally produced 59 EJ by renewable energy sources and biomass contribute about 48 EJ to this amount. Approximately two-thirds of biomass were used for direct combustion in developing countries to provide fuel for cooking and heating. In industrialized countries is biomass used for industrial applications within the heat, power and transportation sectors and for heating in private sector. Global potential of energy produced from biomass has been studied by many authors (Berndes et al., 2003; Heinimö and Junginger, 2009; Thrän et al., 2010; Fiorese at al., 2014). However, most of studies are aimed on overall biomass potential for energy, while studies focused on residues are more of regional character. Berndes et al. (2003) made a comlex review study of 17 different estimations by different authors for prediction of future global biomass potential. Based on these studies is potential biomass energy production estimated to be 100-400 $EJ.year^{-1}$ by 2050. This great variance in estimations is caused by factors, such as land availability, energy crops yield, availability of forest and agriculture residues which vary significantly in these studies. Moreover, use of different scenarios in calculations impacts final results. Thrän et al. (2010) analyzed 19 different studies to predict biomass and energy crops potential in future. The maximum potential energy which could be observed from residual biomass by 2100 can reach 300 $EJ.year^{-1}$. However, majority of analyzed studies congruently claims that this potential will not exceed 100 $EJ.year^{-1}$. Nevertheless, stability of biomass production from agriculture and forest residues is higher than that of energy crops for future predictions. Potential for energy crops is estimated to be between 0-1300 $EJ.year^{-1}$. This great variance is caused by many possible scenarios which can occur during the time, but generally energy crops are more susceptible to changes of economy and political decisions than residues generated within food production.

Scarlat et al. (2010) estimates potential energy value of agricultural crop residues produced within member countries of EU-27 to be 1,530 PJ.year^{-1} while part of residues (40-50 %) would be left in the field for soil maintanance. Panoutsou et al. (2009) presents similar values for EU-27 country members in 2010 and predicts further growth. In 2010 accounted energy potential of agriculture crop residues about 1,634 PJ.year^{-1} and by 2020 should reach 1805 PJ.year^{-1}. Monforti et al. (2015) calculated energy potential of EU-27 countries, considering different rates of biomass removal from the field. Previous studies based on aplication of uniform removal rates for whole region could not estimate precisely energy potential due to large variation of many conditions. Climate, soil type, current farming practices and pre-existing cultivation history determines optimal collection rates for sustainable soil managment. It was found that within arable lands in EU-27 countries could be collect 146,000 kt.year^{-1} of dry matter with potential to produce 2,300 PJ.year^{-1} without impacting the soil organic carbon (SOC) levels (Monforti et al., 2015).

2.3.2. Agriculture crop residues

Along the agriculture sector is produced wide spectrum of different residues from animal or crop production. Moreover, significant amount of residues is produced in the industrial sector where the agriculture products are processed. Residues suitable for energy utilization are produced within food processing industry, paper industry or timber processing industry (Panoutsou et al., 2009). Presently, the most common way of bioenergy is power generation through combustion of lignocellulosic biomass, mainly produced from forestry biomass and agricultural residues (Wen and Zhang, 2015).

Globally is estimated that crop residues are availale in the quantity of 3785×10^6 Mg.year^{-1} and approximately three quarters are made up of cereal residues (Nguyen et al., 2013). The quantities of produced residues and availability of conversion technologies together with regional characteristics are crucial determinants of potential energy production (Rozakis et al., 2013). This study is focused on utilization of crop and plant residual biomass produced directly within agriculture production and their use in thermochemical conversion (combustion). Therefore, this chapter discuss agricultural residues which are researched in this study, and appropriate for thermochemical conversion.

2.3.3. Straw residual biomass

Cereal straw has been used mainly as a fodder, bedding in the stables or as a green manure. Nowadays demand for straw decreases due to intensification and modernization of livestock production. Using of straw for bedding and as a fodder is replaced by new technologies, such as slatted stables or compound feeding. Therefore, is residual straw incorporated back to the soil or burned directly on the fields which causes significant pollution (Abrham and Andert, 2012). In rural areas with lack of fuel wood and other energy sources is straw considered as a valuable energy resource. Agricultural residues constitute one of the important biomass feedstocks in India and China, due to its vast agricultural base and stability of production. The decreasing availability of fuelwood in the most of developing countries is the main driving force for utilization of agricultural residues (Purohit et al., 2006; Zeng et al., 2007).

Significant part of bioenergy production in China is generated by combustion of straw (72 %), mainly by corn and wheat straw (Zhao et al., 2008). Energy produced by straw in rural areas of China represented about 33-45 % of total energy consumption between 1998-2003, whereas in 2002 was produced 620 million tons of straw (Zeng et al., 2007). Fisher et al. (2010) estimates that in Europe is potential of 246 million tons of crop residues by 50 % efficiency of its utilization. Straw as an energy source is also included in European policy for renewable energy sources (Monforti et al., 2015). Despite the straw is abundant, available and cheap source of energy , its utilization is a contoroversial matter due to posibble pollution, depletion of soil, or problems of ash sintering and corrosion during combustion (López-Bellido et al., 2014; Werther et al., 2000).

2.3.4. Problematic aspects of straw utilization

Soil maintanance

Soil organic matter (SOM) is crucial determinant of soil quality and sustainability of crop productivity in intensive agro-ecosystems. Recent research suggests that leaving substantial quantities of residues on the field is advantage for farmers. In fact, agricultural residues are required to maintain (SOM) and prevent erosion while their excessive removal can damage soil quality and reduce fertility. However, conservative removal rates can provide a sustainable biomass resource which can be used in bioenergy (López-Bellido et al., 2014). According to Zheng et al. (2015) retention of residual straw substantially increased SOM in the Huantai county, in northern China. During 1982-1996 straw retention practice had not been implemented and increased of SOM was relatively small. Between 1996-2011, after implementing straw retention practices in region, the rate of SOM content was approximately twice that of 1982-1996. In long-term modelling of soil organic carbon (SOC) content was found that removing of 50 % of straw residues would reduce SOC content by 2.5-10.9 % in 50 years, whereas most important factors are soil, climate and intensity of production (Saffih-Hdadi and Mary, 2008).

Bulk density

Bulk density is crucial factor for utilization of the most of biomass and straw especially. The bulk density of material is in relation with transport and storage costs which are substantial in the energy use of straw materials. While the loose straw have bulk density about 20-40 $kg.m^{-3}$, pressed pellets can reach 560-700 $kg.m^{-3}$ (McKendry, 2002b). Harvested straw is uneasily manipulable, therefore is loose biomass densified into some form of defined shape and density. Common form are straw bales which bulk density ranges between 60-500 $kg.m^{-3.}$ Bales can be used for further processing or combustion in specially adapted facilities for energy generation. More densified forms are briquettes and pellets which bulk density can reach 600-1200 $kg.m^{-3}$ and 1000-1200 $kg.m^{-3}$, respectively. Stolarski et al. (2013a) reported bulk density of willow chips and rape straw to be 180 $kg.m^{-3}$ and 130 $kg.m^{-3}$, respectively. After briquetting was increased bulk density to 469 $kg.m^{-3}$ and 395 $kg.m^{-3}$, respectively.

Ash content and sintering

The ash content in crop residues varies according to the type of material. While wood contains usually less than 1 % of ash, wheat straw contains about 4 % and barley straw can contain about 6 % (McKendry, 2002b). High ash content is usually indicator of the abundant alkaline earth metals. These substances have low fusion temperature which leads to the slagging of ash, as well as to corrosion effect on the metal parts of combustion chambers and equipment (Chen et al., 2009). Significant decrease in ash content can be reached by leaving straw residues to leach on the fields which is practised in the cultivation of energy grasses. In the case of cereal straw is this practice impossible due to necessity of harvesting grain in certain time.

Emissions

Emissions released during combustion are one of the most monitored properties in the biofuel sector. Since the CO_2 released during combustion of crop biomass is equal to the fixed CO_2 during growing plants, biomass does not contribute to a build up of CO_2 in the atmosphere (Havrland et al., 2011). Harmful impact on environment is related to emissions of CO, SO_2 and NOx which are related to the content of S and N in the biomass, as well as to the conditions of burning (i.e. excess of air) (Koloničný, 2010). The straw has generally higher content of N in compare to woody biomass. McKendry (2002a) measured percentage of N content in the typical sources of biomass, such as wood (average), wheat straw and rice straw. Percentage of N were measured to be 0 %, 0.3 % and 0.7 %, respectively. CO emissions were related to the parameters of combustion, such as excess of air or inapropriatness of combustion facility. Morissette et al. (2013) studied emissions released during combustion of the corn stover and wheat straw bales in special combustion chamber. Average emissions of CO, NOx and SO_2 for the corn stover were 2725; 9.8 and 2.1 $mg.m^{-3}$, respectively and for the wheat straw were 2210; 40.4 and 3.7 $mg.m^{-3}$, respectively. Within the the straw biomass vary released emissions significantly. Zhang et al. (2008) presents comparison of NO_x, CO, CO_2 emissions of rice straw, wheat straw and corn straw. The emission factors of CO and CO_2 followed the order of wheat straw > corn straw > rice straw. In contrast for emissions of NOx were observed the order of rice straw > corn straw > wheat straw.

2.3.5. Pruning and tree maintanance residues

Common agricultural woody residues can be obtained from different agriculture systems, such as vineyards, olive tree systems or from orchards. These residues can be used for energy generation, as well as straw residues. Nowadays are pruning residues usually destroyed in the field or crushed onto the soil, so there is no direct economic benefit (Velázquez-Martí et al., 2011a). Furthemore, woody residues from vineyards and orchards are often land-filled near the field which increases risk of serious problems due to possible spreading of pathogens and parazites originate from these spots (Cavalaglio and Cotana, 2007; Romański et al., 2014). Nowadays, is also preferred anti-erosion soil managment within orchards and vineyards which includes mostly covering surface between the rows by perennial grasses which decreases need to use of these rediues as a mulching material. Therefore, collecting of this residual biomass and its use as a source of energy could provide additional economic benefits to producers (Velázquez-Martí et al., 2011a). According to Magagnotti et al. (2013) could pruning residues replace traditional wood resources for energy and industrial use, as well as supplying bioenergy plants with renewable fuel.

The yields of biomass are dependent on tree species and the way of cultivation, e.g. pruning intensity, shape of tree or age of tree. Crucial factor in utilization of pruning residues is performance of mechanization for harvesting residues and transportation distance which significantly influence final costs of production (Spinelli et al. 2010). In vineyard production is yield of residues dependent on the structure of plantation, variety and irrigation. Velázquez-Martí et al. (2011b) found that withi grapevines is higher quantity of biomass produced by varieties cultivated for fresh fruit than by wine producing varieties which is also related to different structures of plantantions. The shape of horizontal trellis for fresh fruit production produce 4.2 $t.ha^{-1}$ of dry biomass which is more than triple of the amount produced by standard trellis shape. In the wine production was not observed difference between biomass production of standard trellis shape and vase shape which was equally 0.8 $kg.tree^{-1}$ for both shapes. However, standard trellis shape gives 2.15 $t.ha^{-1}$ of dry biomass while the yields of vase shape vineyard are 25 % lower. Irrigation is also significant factor which increases the yield of dry matter about 42 % in this case.

The effective performance of mechanization is necessary for sustainable and economical use of residues. Since the orchards and vineyards are of specific structure, construction and composition, the mechanization for collecting residues have to be adjusted. Magagnotti et al. (2013) tested available harvesting machines for residues produced in the vineyards and in the apple and pear orchards. Based on 17 different field tests was found that amount of harvested residues was 2.3 and 3.5 $t.ha^{-1}$, respectively for the vineyards and for the orchards. However, the real potential was 3.1 $t.ha^{-1}$ for vineyards and 3.9 $t.ha^{-1}$ for the orchards, but due to performance of machines was on the field left significant amount of residues. Therefore, harvesting losses ranged from 3.4 % to 61.9 % of the total residues on site with no significant differences between machines. The amount of harvested residues can not be compared with the annual productivity of cereal straw residues. However, in some areas where the straw is used different way (e.g. soil improvement, fodder) could pruning and maintanance residues play significant role as a source of energy.

Cavalaglio and Cotana (2007) estimate yields of pruned biomass for different trees cultivated in Italy. The highest estimated residue yield was calculated for vineyards and peach trees (2.9 $t.ha^{-1}$), while the highest ratio of residue/product was observed in the almond trees and hazel trees, as shown in the ***Table 3***.

Table 3.: Values of residues ($t.ha^{-1}$) and ratio of residue/product (wet basis) in Italy

Plants	Residue ($t.ha^{-1}$)	Residue/product
Vineyard	2.9	0.2-0.8
Olive trees	1.7	0.5-2.6
Apple trees	2.4	0.1
Pear trees	2	0.1
Peach trees	2.9	0.2
Citrus tress	1.8	0.1
Almond trees	1.7	1.9
Hazel trees	2.8	1.9

Source: Cavalaglio and Cotana (2007)

Utilization of pruning and maintanance residues is limited due to technological aspects which restrict using of these materials for energy production. Economic viability is crucial in this time and if the collection and processing costs exceed the costs of normal energy production there will be no stimulus for utilization of these residues. Spinelli et al. (2010) researched different costs of recovering of vineyard pruning residues by different technologies in Italy. The lowest cost for harvesting of 1 ton was observed in the case of small-scale tractor with attached comminuter with build-in dumping bin and the cost was 30-40 $€.t^{-1}$. Lower cost of this harvesting method is related to the processing in compare to bale harvester because the whole bales can not be fed directly to the burning chambers and have to be comminuted additionally. This cost is favourable from the viewpoint of sustainable production, since the price offered for energy biomass in Italy reach 50-55 $€.t^{-1}$. The effect of material properties has substantial role in the effectivness of its energy use, as well as economic viability. Moisture content of harvested material is crucial for storage and afteward combustion. Higher moisture content of material causes problems with storage, feeding process and reduce the heat yields of combustion process. Drying of these materials can be relatively cost and time demanding. Velázquez-Martí et al. (2011b) found, that vineyard prunings of 48 % of moisture content dried in open air conditions require 25 days to decrease the moisture content to minimum of 20 % while in drying oven were absolutely dried within 5 days. The structure of material also influences the properties and ways of utilization for energy. Particle size distribution is crucial for the fuel handling properties and influences also energy conversion efficiency and emission rates during combustion. The particles smaller than 3 mm represent a health hazard because they reduce air circulation during storage, supporting bacteria proliferation, with an increased risk of spontaneous combustion (Spinelli et al., 2011).

Additional costs for harvesting of residues could not be include in the case of Sea buckthorn because the whole branches have to be cut of the plant together with berries for further processing. The amount and properties of wood are crucial factor in utilization of this material for energy. However, the amount of SBT residues have not be researched by any authors and therefore is included as one of the objectives in this study.

III. AIMS OF THE THESIS

3.1. Aims of the Thesis

The overall (main) Thesis objective was to assess the use of Sea buckthorn (SBT) residual wood for energy production in the form of briquettes. For meeting the overall objective wood yield potential in orchard cultivation was measured and briquettes made of SBT wood as well as combined briquettes were tested and their technical parameters were compared with selected biofuel standards.

Specific Thesis objectives and hypotheses can be formulated as follows:

1. Determination of the yield of SBT residual woody biomass in orchard cultivation
2. Assesment of properties of briquettes made from SBT wood
3. Assesment of properties of briquettes made from combination of SBT wood and residual straw

3.2. Hypotheses

Hypotheses 1: Briquettes made from SBT woody biomass meet the international standard for graded wood briquettes according to ISO 17225-3:2014(E).

Hypotheses 2: Use of SBT wood in the mixture with residual straw (wheat and rape) largely improves technical properties of briquettes made from pure straw according to ČSN EN ISO 17225-1.

IV. MATERIAL AND METHODS

4.1. Materials

Residual wood of Sea buckthorn (*Hippophae rhamnoides*) variety Leikora produced during harvest of berries in large-scale orchard was obtained from the company Ekoplanet which grows about 100 ha of SBT in Ohrazenice, Czech Republic. Chopped wheat straw and rape straw were obtained from the company ATEA PRAHA, s.r.o. producing pellets from residual straw materials.

4.2. Drying of material

Chopped wheat straw and rape straw were obtained with moisture content below 15 %, therefore no additional drying was necessary. Conversely, obtained SBT wood had moisture content between 24-29 %, even it has been stored under the open roof pen for one year, as shown in the ***Figure 5***. For the purpose of briquetting was necessary to decrease moisture content of wood below 15 %, as given by ČSN EN ISO 17225-3. Chipped wood was spread on the sheet in the technical hall of VÚZT and the whole mound has been turned once a day until the moisture content decreased below 15 %. Final moisture content of SBT wood was found to be 14.5 %.

Figure 5.: SBT residual wood stored under open roof pen

4.3. Grinding of the raw material

Residual SBT wood in the form of whole branches was ground using woodchipper Pezzolato PZ 110MB, borrowed by VÚZT. For comparison of the effect of different particle size on briquettes properties was part of wood chips ground again using hammer mill type 9FQ - 40C (power 7.5 kW) (Pest Control Corporation), as shown in the ***Figure 6***. Wood chips were ground with hammer mill screen size 10 mm and both fractions of material are shown in the ***Figure 6***.

Figure 6.: Wood chips and crushed wood chips (left) and grinding of the wood chips on hammer mill type 9FQ - 40C (right)

4.4. Mixing the material

For production of briquettes from mixtures of SBT wood chips and straws were materials weighted and mixed in three different ratios. Mixtures were prepared in two different combinations (SBT wood chips: wheat straw, SBT wood chips: rape straw) and mixed in the weighted ratios (wood chips : straw): 2:1; 1:1; 1:2. Universal mixer was borrowed by VÚZT, v.v.i. Praha, as shown in the ***Figure 7***.

Figure 7.: Universal mixer

4.5. Briquetting

Briquettes were made in cooperation with VÚZT, v.v.i. Praha using the hydraulic piston briquetting press Brikstar 30 - 12 with power input 4.4 kW and production capacity of 40-60 kg.h^{-1}. Press is shown in the ***Figure 8***. The own press consists of bin for material and hydraulic piston with attached conical tube and produces briquettes of cylindrical shape which are shown in the ***Figure 9***. The briquetting piston chamber used in this study was of diameter 65 mm which affects final diameter of produced briquettes. Briquettes produced from mixtures of SBT wood and straw in different ratios are shown in the ***Figure 10*** and ***Figure 11***.

Figure 8.: Briquetting press Brikstar 30 - 12

Figure 9.: Briquettes made from pure materials SBT wood chips (left), wheat straw (middle), rape straw (right)

Figure 10.: Briquettes made from different mixtures of SBT wood and rape straw

Figure 11.: Briquettes made from different mixtures of SBT wood and wheat straw

4.5. Determination of wood yield

As a study area was selected 8-year old SBT orchard in village Ohrazenice, Czech Republic. The orchard was established in 2007 by planting variety *Leikora* with plant spacing 1.5 × 4 m and ratio of male to female plants approximately 1:10. The size of orchard is approximately 65 × 45 m and plants are grown on the area 60 × 40 m. For measuring yield were selected three plots of size 10 × 5 m. The plots location within the orchard was selected in order to represent wood yields from the whole orchard. The ***Figure 12*** shows plant spacing within orchard and selected plots for measuring wood yield. For calculation of wood yield of dry basis (d.b.) matter was measured moisture content of wood before drying. The total yield was calculated according to ***formula (1)*** where the average yield per harvested tree was extrapolated on the area of one hectare. This yield was further divided by number of years between harvests and final wood yield was expressed in $kg.ha^{-1}.yr^{-1}$. Harvest was done in the September 2014 according to common agriculture practices done by Ekoplanet company. For removal of fruiting branches were used garden and hydraulic scissors. After that were whole branches transported to the freezing box and stored for further processing. Frozen branches with berries and leaves were than removed from boxes and manually shaked to remove berries and rests of the leaves, as shown in the ***Figure 13***. The amount of separated branches harvested from each tree was weighted by using hanging weight KERN CH 50K50 and recorded, as shown in the ***Figure 14***.

$$Y_t = \frac{Y_{tr} \times N_{tr}}{I_h}; \ (\mathbf{kg.ha^{-1}yr^{-1}}) \quad (1)$$

where: $\mathbf{Y_{tr}}$ - Yield per tree (kg)
$\mathbf{N_{tr}}$ - Number of trees per hectare
$\mathbf{I_h}$ - Interval between harvests (years)
$\mathbf{Y_t}$ - Total yield ($kg.ha^{-1}.yr^{-1}$)

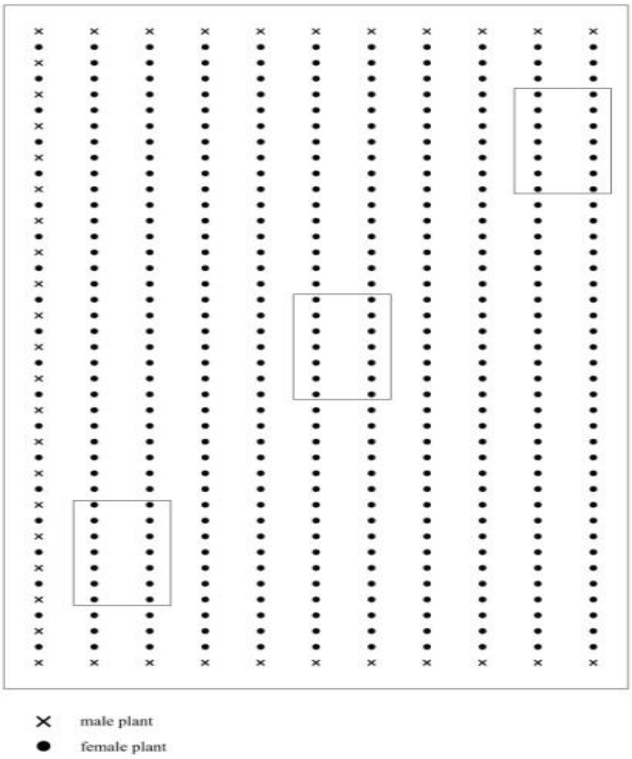


Figure 12.: Orchard layout and selected plots

Figure 13.: Frozen fruiting branches before shaking (left) and branches after removal of berries (right)

Figure 14.: Weighting of residual wood (left) and harvested hedgerow in 8-year old orchard (right)

4.6. Determination of normative specifications of briquettes

4.6.1. Determination of origin and source of biomass

The briquettes made from SBT wood were classed according to the table included in the standard ISO 17225-3:2014(E). Briquettes made from combination of SBT wood and straw were classed according to ČSN EN ISO 17225-1.

4.6.2. Determination of diameter (*D*), length (*L*) and shape

The diameter and length were determined for produced cylindrical briquettes according to the ISO 17225-3 and ČSN EN ISO 17225-1 by using Vernier calliper for measuring of dimensions. From each type of produced briquettes were selected 10 briquettes and the dimensions were measured. The average was used for interpretation of results, as well as standard deviation within each tested dimension. Measuring of dimensions by Vernier calliper is shown in the ***Figure 15***.

Figure 15.: Measuring the diameter of SBT briquette by Vernier calliper

4.6.3. Determination of moisture content

Moisture contents of SBT wood and residual rape and wheat straw were determined according to ČSN EN 14774-1. For determination was used drying oven Memmert model 100 - 800 equipped with timer and volume of the chamber about 100 dm^3. The drying oven with samples is shown on the ***Figure 16***.

The principle of determination: The samples placed in the beakers were weighted on laboratory scale. Samples in beakers were placed into the drying oven and for 8 hours at temperature 105 °C. After drying were beakers with samples cooled for about 3 minutes and weighted. The moisture content was calculated according to ***formula (2)***:

$$\boldsymbol{w} = \left(\frac{\mathbf{m_w} - \mathbf{m_d}}{\mathbf{m_w}}\right) \times \mathbf{100};\ (\%) \qquad (1)$$

where: $\mathbf{m_w}$- weight of wet sample before drying (g)
$\mathbf{m_d}$- weight of dried sample (g)
w - moisture content (%)

Figure 16.: Drying oven Memmert model 100 - 800 with samples

4.6.4. Determination of ash content

Ash content was determined according to ČSN EN 14775. Ash content is determined by calculation of weight of the inorganic residue after combustion of sample in the controlled temperature. Analytical samples were crushed down to the particle size lower than 1 mm and dried in the drying oven before determination. In the first stage is temperature continually increased for 30-50 minutes up to 250 °C. In the second stage is temperature further increased for 30 minutes up to temperature 550°C which is held for at least 120 minutes to achieve absolute combustion. Each sample was determined twice and as result is considered arithmetic mean of these two measurements, whereas the difference between two measurements did not exceed 0.2 %. Measured ash content was calculated according to ***formula (3)***. For the mixtures was ash content calculated on the basis of weighted ratios in each mixture. Samples were analyzed in laboratory of VÚZT, v.v.i. Praha and ash content was described as a weight percentage.

$$\mathbf{A_d} = \frac{\mathbf{m_3 - m_1}}{\mathbf{m_2 - m_1}} \times \mathbf{100} \times \frac{\mathbf{100}}{\mathbf{100 - M_{ad}}};\ (\%) \qquad (3)$$

where: $\mathbf{m_1}$ - weight of the beaker (g)
$\mathbf{m_2}$ - weight of beaker with sample (g)
$\mathbf{m_3}$ - weight of beaker with ash (g)
$\mathbf{M_{ad}}$ - moisture content of tested sample (%)
$\mathbf{A_d}$ - ash content in anhydrous condition (%)

4.6.5. Determination of particle density

Particle density was determined according to ČSN EN ISO 15150. For estimation of particle density was used principle of stereometric means. From each type of mixtures were selected 10 briquettes and mean values of dimensions were used for calculation. By using Vernier calliper and digital weight KERN KBJ 650-2NM (***Figure 17***) were measured dimensions and weights of briquettes and particle density was calculated according to ***formula (4)***.

$$\boldsymbol{\rho} = \frac{\mathbf{m}}{\mathbf{r^2 . l . \pi}};\ (\mathbf{g . cm^{-3}}) \qquad (4)$$

where: $\boldsymbol{\rho}$ **-** particle density
r - radius of briquette (cm)
l - length of briquette (cm)
m- weight (g)
$\boldsymbol{\pi}$ **-** constant number (3.14)

Figure 17.: Vernier calliper and digital balance

4.6.6. Determination of net calorific value

Net calorific value (NCV) of produced briquettes was determined as calorific value of raw materials and calculated according to ČSN EN ISO 14918. For determination was used calorimeter Laget MS-10A with accessories, as shown in the ***Figure 18***.

The principle of determination: The calorific value was determined in a bomb calorimeter. Samples of dried and weighted material were burned in the oxygen atmosphere in a stainless steel high-pressure vessel (bomb). The vessel with sample was placed in a calorimeter which contains a known volume of water with a known temperature. The combustion products CO_2 and H_2O are allowed to cool to the standard temperature. The result heat of combustion is measured from the accurate measurement of the rise in the temperature of water in the calorimeter, the calorimeter itself and the vessel. This way determined calorific value is the gross calorific value ($\mathbf{Q_{gr}}$) which is calculated according to the ***formula (5)***:

$$\mathbf{Q_{gr}} = \frac{[\mathbf{dT_k} \times \mathbf{T_k} - (\mathbf{c_1}+\mathbf{c_2})]}{\mathbf{m}}\ (\mathbf{J.g^{-1}}) \tag{5}$$

where: $\mathbf{dT_k}$ - temperature jump (°C)

$\mathbf{T_k}$ **-** heat capacity of calorimeter = 9107 $J.°C^{-1}$

$\mathbf{c_1}$ **-** repair of benzoic acid= 20 J

$\mathbf{c_2}$ **-** repair of the heat released by burning spark fine wire = 70 J

m - weight of material sample (g)

Net calorific value ($\mathbf{Q_{net}}$) is calculated according to ***formula (6)***, while using average hydrogen content in biomass ($\mathbf{H_a}$**= 5.5 %**):

$$\boldsymbol{Q_{net}} = \boldsymbol{Q} - \mathbf{24.42} \times (\boldsymbol{w} + \mathbf{8.94} \times \boldsymbol{H_a});\ (\boldsymbol{J.g^{-1}}) \tag{6}$$

where: $\mathbf{Q_{gr}}$ - gross calorific value ($J.kg^{-1}$)

24.42-coefficient corresponding to 1% of the water from the sample at 25°C ($J.kg^{-1}$)

w - water content in the sample (%)

8.94 - coefficient for the conversion of hydrogen to water

$\mathbf{H_a}$ - hydrogen content in the sample (%)

Figure 18.: Calorimeter Laget MS-10A with accessories

4.6.7. Determination of nitrogen, sulfur and chlorine content

Nitrogen was determined according to ČSN EN 15104 by semi-micro Kjeldahl method using Kjeltec analyzer. Principle of this method is burning of the sample in the oxygen or other carrier gas. As a result of this reaction is ash and gaseous products of combustion. Products of combustion which can affect the determination was removed and nitrous oxides were reduced to elementary nitrogen. Weighted fraction of nitrogen were afterwards quantatively determined from the gas stream by instrumental analysis of gases. Given results were calculated and expressed as weighted percentage according to ***formula (7)***.
Sulfur and chlorine contents were determined according to ČSN EN 15289. Element analysis was done by automatical device using x-ray fluorescence analyzer Niton XL3t GOLLD+ in the laboratory of VÚZT, v.v.i. Praha. Results are described as a weight percentage of dry matter.

$$\mathbf{N_d} = \mathbf{N_{ad}} * \frac{\mathbf{100}}{\mathbf{100 - M_{ad}}};\ (\%) \tag{7}$$

where: $\mathbf{N_d}$- nitrogen content in water-free state
$\mathbf{N_{ad}}$- determined nitrogen
$\mathbf{M_{ad}}$- moisture in analytical sample for general analysis

4.6.8. Determination of Cl, As, Cd, Cr, Cu, Pb, Hg, Ni, Zn content

All contents of minor elements were determined according to ČSN EN 15297 in Laboratory of Environmental Chemistry CULS Prague.

4.6.9. Determination of mechanical durability

The mechanical durability of produced briquettes was tested according to ČSN EN 15210-2 by using equipment borrowed from Technical Faculty, CULS. For determination of mechanical durability was used rotating steel cylindrical abrasion drum with a nominal volume 160 litres (depth 598 mm, inner diameter 598 mm). The drum was equipped with rectangular steel partition (length 598 mm, height 200 mm) to lift and drop sample of briquettes within each rotation, as shown in the ***Figure 19***.

The working procedure: Samples of each type of briquettes were weighed to reach the total mass of 2 kg (± 0.1 kg). The sample was then rotated in abrasion drum for 5 minutes on 21 revolutions per minute. The mechanical durability (**DU**) was then calculated according to ***formula (8)***:

$$\mathbf{DU} = \frac{\mathbf{m_A}}{\mathbf{m_E}} \times \mathbf{100};\ (\%) \qquad (8)$$

where: $\mathbf{m_A}$ – weight of briquettes after durability testing (g)
$\mathbf{m_E}$ – weight of briquettes before durability testing (g)

From results of five parallel drum trials for each type of briquettes the average value of mechanical durability was calculated and then rounded to the closest 0.1 %.

Figure 19.: Cylindrical abrasion drum

V. RESULTS

5.1. Yields of woody biomass

Yields of weighted biomass per harvested tree are shown in the ***Table 4***. Based on the found average yield per tree was calculated average wood yield per hectare according to ***formula (1)***. For calculation of yield per year was total yield divided by number of years in harvest cycle which is usually two years. Yield of wood per hectare is affected by plant spacing, average yield per tree and number of harvested trees per hectare, as shown in the ***Table 5***.

Table 4.: Measured wood yields within tested orchard

	Wood yields per tree (kg.tree^{-1})		
Tree	Plot 1	Plot 2	Plot 3
1	1.85	1.60	2.05
2	2.05	2.65	1.55
3	1.20	2.15	1.50
4	2.40	1.45	1.80
5	1.70	2.00	2.00
6	1.55	1.60	1.05
7	0.85	1.35	1.95
8	1.70	1.75	1.50
9	2.15	1.90	1.60
10	1.65	1.70	2.25
11	2.40	1.85	1.75
12	1.50	1.10	1.90
13	1.75	1.15	2.80
14	1.90	1.80	1.85
Tree average	1.76 ± 0.32	1.72 ± 0.30	1.83 ± 0.29
Total average		1.77	

Table 5.: Residual wood yield

No. of trees per hectare	Wood yield per tree (kg.tree^{-1})	Wood yield (kg.ha^{-1})	Wood yield per year (kg.ha^{-1}.yr^{-1})	Wood yield of dry matter (kg.ha^{-1}.yr^{-1})
1,515	1.77	2,681.55	1,340.76	965.36

5.2. Properties of briquettes made from SBT wood

Properties of briquettes made from SBT residual wood were determined and assessed according to ISO 17225-3:2014(E) for specifications of graded wood briquettes.

5.2.1. Origin and source of briquettes

According to ISO 17225-1 were briquettes made from SBT wood chips categorized as a 1.2.1. Chemically untreated wood residues.

5.2.2. Diameter (*D*), length (*L*) and shape

Diameter, length and shape is more or less given by used briquetting equipment and material. The diameter is given by dimensions of pressing chamber. In this study was used pressing chamber of diameter 65 mm, therefore diameter of produced briquettes varies around this value and is affected by adhesion properties of material and storage of briquettes after briquetting. The impact of particle size distribution on final dimensions of briquettes is obvious, as shown in the ***Table 6***. Where briquetted SBT wood chips have average length about 49.92 ± 0.010 mm which is less than 57.8 ± 0.001 mm of finer grinded SBT- 10 mm. The shape was specified according to ISO 17225-3:2014(E), as shown in the ***Figure 20***.

Table 6.: Diameter and length dimensions of briquettes made from SBT wood

Material	Diameter (*D*) (mm)	Length (*L*) (mm)
SBT- wood chips	67.08 ± 0.000	49.92 ± 0.010
SBT- 10 mm fraction	67.40 ± 0.00	57.80 ± 0.001

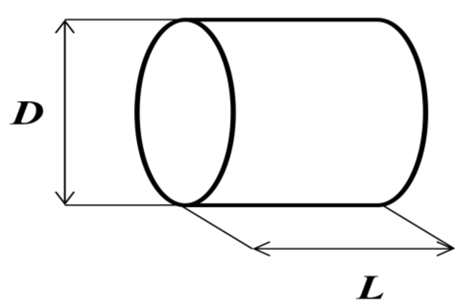


Figure 20.: Shape of produced briquettes

5.2.3. Moisture content

Moisture content (MC) was determined on raw materials before briquetting. The result is shown in the ***Table 7***. According to ISO 17225-3:2014(E) SBT wood fulfill limitations for briquette categories A2 and B. In these categories is required moisture content below 15 %, and therefore could be SBT briquettes classified into category M15.

Table 7.: Moisture content of raw material

Material	MC (%)
SBT wood	14.5 ± 0.2

5.2.4 Ash content

Content of ash in SBT wood was determined in the laboratory of VÚZT, v.v.i. according to ČSN EN ISO 14775. Measured ash content was found to be 0.48 % which classed SBT wood to the category A1 according to ISO 17225-3:2014(E).

5.2.5. Particle density

Particle density of briquettes made from SBT wood was affected by the size of particles, as shown in the ***Table 8***. The effect of particle size on briquettes density was found to be crucial. In the case of briquettes made from SBT wood chips was found higher particle density than in the briquettes made from finer crushed wood on the hammer mill. The impact of wood homogenization on accuracy of measurement is obvious from standard deviations. The accuracy of measurment is probably given by different distribution of particle size in wood chips and finer crushed wood, as shown in the ***Table 8***. In the case of wood chips was particle size distribution less uniform than in the case of crushed wood. Standard deviation is therefore lower in the case of crushed wood measurements, as shown in the ***Table 8***.

Table 8.: Particle density of briquettes made from SBT wood

Material	Particle density ($g.cm^{-3}$)
SBT- wood chips	0.837 ± 0.025
SBT- 10 mm fraction	0.786 ± 0.011

5.2.6. Net calorific value

The net calorific value (NCV) of SBT wood was calculated on the basis of gross calorific value and moisture content. According to ISO 17225-3:2014(E) SBT wood fulfills NCV requirements of category A1 of graded wood briquettes which is given by NCV higher than 15.5 $MJ.kg^{-1}$. The results of NCV are shown in the ***Table 9***.

Table 9.: Net calorific value of SBT wood

Material	NCV ($J.g^{-1}$)
SBT wood	17,184.47

5.2.7. Nitrogen, sulfur and chlorine

Determination of N, S, Cl content were done according to ČSN EN ISO 15104 for nitrogen content and according to ČSN EN ISO 15289 for sulfur and chlorine contents. All measurements were done in the laboratory of VÚZT, v.v.i. and results are shown in the ***Table 10***.

Table 10.: Content of N, S, Cl elements in SBT wood (%)

Material	N (%)	S (%)	Cl (%)
SBT wood	0.72	0.68	0.09

5.2.8. Minor elements

The contents of minor elements was determined in Laboratory of Environmental Chemistry CULS Prague. As a minor elements were determined contents of Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni) and Zinc (Zn). All contents were detemined according to ČSN EN 15297 and results are shown in the ***Table 11***.

Table 11.: Content of minor elements in SBT wood

Element	Content ($mg.kg^{-1}$)
Arsenic (As)	0.024
Cadmium (Cd)	0.038
Chromium (Cr)	0.503
Copper (Cu)	3.171
Lead (Pb)	0.129
Mercury (Hg)	0.048
Nickel (Ni)	0.657
Zinc (Zn)	6.865

5.3. Properties of briquettes made from mixtures of SBT wood and residual straw

From the viewpoint of energy utilization is SBT wood less important due to lower wood yields in compare to other biomass sources. Therefore, its use as an alone agrofuel is not viable in current state of SBT production in Czech Republic. However, properties of this wood can be helpful in the form of combined briquettes with other agriculture residues, such as residual straw. From this reason were produced briquettes from combination of SBT wood and wheat straw, and SBT wood and rape straw in different weighted ratios to study the impact of SBT wood as improving additive for straw biofuel briquettes. The briquettes specifications were tested and compared according to the ČSN EN ISO 17225-1 for normative and informative specifications of briquette properties.

5.3.1. Origin

Since the briquettes were designed and produced in combinations of different biomass sources, the produced briquettes were classed to the category 5. Homogenous mixtures and mixtures. For mixtures was used herbaceous biomass (residual straw) and wood biomass (SBT wood).

5.3.2. Diameter (*D*), length (*L*) and shape

Measured dimensions of briquettes produced from pure materials are shown in the ***Table 12***. Briquettes made from pure materials show higher dimension uniformity in compare to briquettes made from mixtures, as shown in the ***Table 13*** and ***Table 14***. On the basis of standard deviations was found that highest variability in diameter dimensions showed briquettes made from mixture of SBT : Wheat straw (2:1). The highest variability in length dimension was found in the case of briquettes made from the mixture SBT : Rape straw (2:1).

Table 12.: Diameter and length dimensions of briquettes made from pure materials

Material	Diameter (*D*) (mm)	Length (*L*) (mm)
SBT wood chips	67.08 ± 0.000	49.92 ± 0.010
Wheat straw	64.44 ± 0.000	31.68 ± 0.007
Rape straw	69.96 ± 0.001	63.14 ± 0.004
SBT- 10 mm	67.40 ± 0.00	57.80 ± 0.001

Table 13.: Diameter and length dimensions of briquettes made from mixtures of SBT wood and rape straw

Material	Diameter (*D*) (mm)	Length (*L*) (mm)
SBT : Rape straw (2:1)	67.12 ± 0.576	65.42 ± 13.856
SBT : Rape straw (1:1)	67.28 ± 0.736	54.18 ± 8.376
SBT : Rape straw (1:2)	67.66 ± 0.368	78.23 ± 6.065

Table 14.: Diameter and length dimensions of briquettes made from mixtures of SBT wood and wheat straw

Material	Diameter (*D*) (mm)	Length (*L*) (mm)
SBT : Wheat straw (2:1)	65.80 ± 0.869	42.58 ± 2.704
SBT : Wheat straw (1:1)	66.04 ± 0.512	42.66 ± 3.848
SBT : Wheat straw (1:2)	65.96 ± 0.736	38.04 ± 5.368

5.3.3. Moisture content

MC of SBT wood, wheat straw and rape straw were determined separately for each material before briquetting process, as shown in the ***Table 15*** and after briquetting for all produced briquettes, as shown in the ***Table 16*** and ***Table 17***. Differences of MC between raw materials and briquetted one could be caused by higher temperatures in briquetting chamber and by the conditions of storage and handling. MC of produced briquettes was determined within few days after briquetting which could affect final moisture content. However, storage and handling conditions of tested briquettes were designed to minimize effect of drying or moisturizing, the final moisture content of produced briquettes was lower than of raw materials.

Table 15.: MC of raw materials before briquetting operation

Material	MC (%)
SBT	14.50 ± 0.225
Wheat straw	13.20 ± 0.320
Rape straw	12.50 ± 0.045

Table 16.: MC of briquettes made from mixtures of SBT wood and wheat straw

Material	MC (%)
SBT wood	13.62 ± 0.005
SBT : Wheat straw (2:1)	13.48 ± 0.285
SBT : Wheat straw(1:1)	13.14 ± 0.145
SBT : Wheat straw(1:2)	12.97 ± 0.210
Wheat straw	12.85 ± 0.050

Table 17.: MC of briquettes made from mixtures of SBT wood and rape straw

Material	MC (%)
SBT wood	13.62 ± 0.005
SBT: Rape straw (2:1)	12.93 ± 0.145
SBT: Rape straw (1:1)	12.26 ± 0.075
SBT: Rape straw (1:2)	11.83 ± 0.025
Rape straw	11.44 ± 0.100

5.3.4. Ash content

The lowest ash content was found in SBT wood (0.48 %) while straw materials show contents higher than 7 %, as shown in the ***Table 18*** and ***Table 19***. Ash content is crucial property of fuel in the process of burning. Higher amounts of ash in herbaceous biomass often complicates process of burning by blocking the inlets of air to the chamber. By additivation of SBT wood to the straw briquettes was achieved lower ash content of these briquettes and their improvement from the viewpoint of lower ash content. Since wheat and rape straw contain relatively high amount of ash in compare to wood, the final briquettes made from mixtures were affected mostly by this fact. According to ČSN EN ISO 17225-1 could be all briquettes classed to the category A10.0 with ash content ≤ 10.0 %.

Table 18.: Ash content of briquettes made from mixtures of SBT wood and wheat straw

Material	Ash content (%)
SBT wood	0.48
SBT : Wheat straw (2:1)	2.76
SBT : Wheat straw (1:1)	3.91
SBT : Wheat straw (1:2)	5.05
Wheat straw	7.33

Table 19.: Ash content of briquettes made from mixtures of SBT wood and rape straw

Material	Ash content (%)
SBT wood	0.48
SBT : Rape straw (2:1)	2.93
SBT : Rape straw (1:1)	4.16
SBT : Rape straw (1:2)	5.39
Rape straw	7.84

5.3.5. Particle density

The particle density of briquettes produced from pure materials ranges between 0.627 g.cm^{-3} for rape straw and 0.903 g.cm^{-3} for wheat straw, as shown in the ***Figure 21***. In the case of briquettes made from SBT wood chips was achieved higher particle density than in the briquettes made from finer crushed SBT wood. Briquettes made from mixtures correspond more or less to the particle densities of briquettes from pure materials. While adding SBT wood chips to the wheat straw briquettes decreased their particle density. Conversly, adding of SBT wood to the rape straw briquettes increased particle density, as shown in the ***Figure 22*** and ***Figure 23***. All briquettes made from mixture of SBT wood and wheat straw met the requirements of ČSN EN ISO17225-1 for particle density ≥ 0.8 g.cm^{-3} and could be classed to the category DE0.8. The highest particle density of all observed briquettes was found in the pure wheat straw briquettes which exceed 0.9 g.cm^{-3} and could be classed to the category DE0.9 with particle density ≥ 0.9 g.cm^{-3}.

The effect of addition of SBT wood to rape straw briquettes was opposite than in the case of wheat straw. However, the particle density increased with addition of SBT wood, briquettes from this mixture did not fulfill requirements of ČSN EN ISO 17225-1 for particle density ≥ 0.8 g.cm^{-3}. The lowest particle density 0.621 ± 0.017 g.cm^{-3}, was found in the mixture of SBT : Rape straw (1:2) which was lower than in the case of pure rape straw briquettes. If the higher particle density is understood as a improving property of briquettes, the additon of SBT wood to the rape straw briquettes improved this briquettes, even if the normative requirements of ČSN EN ISO17225-1 was not met in this case. Conversely, the addition of SBT wood to the wheat straw briquettes negatively affect their particle density.

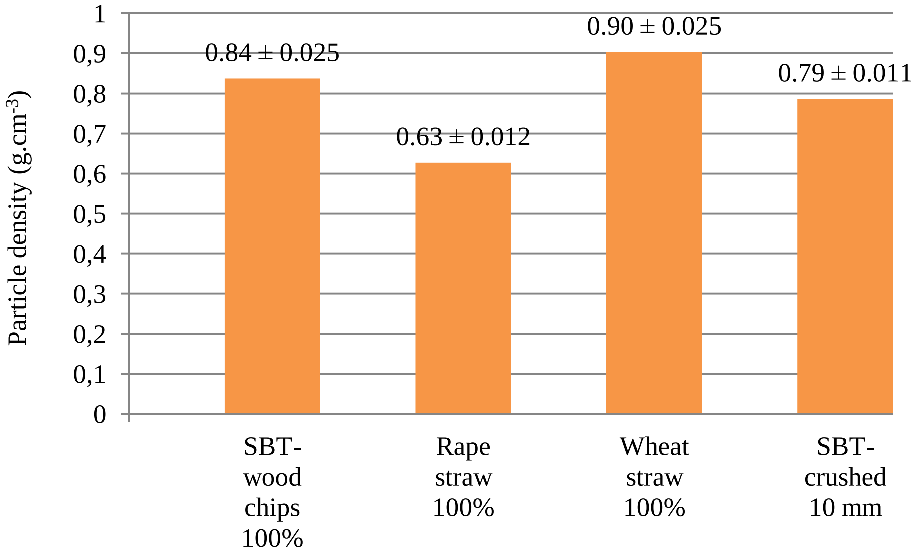


Figure 21.: Particle density of briquettes made of SBT wood, wheat straw and rape straw

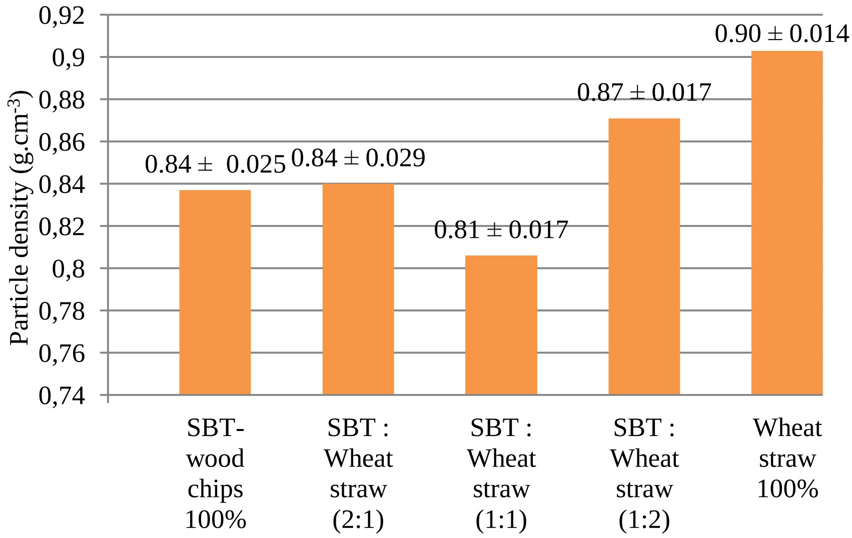


Figure 22.: Particle density of briquettes made from SBT wood and wheat straw

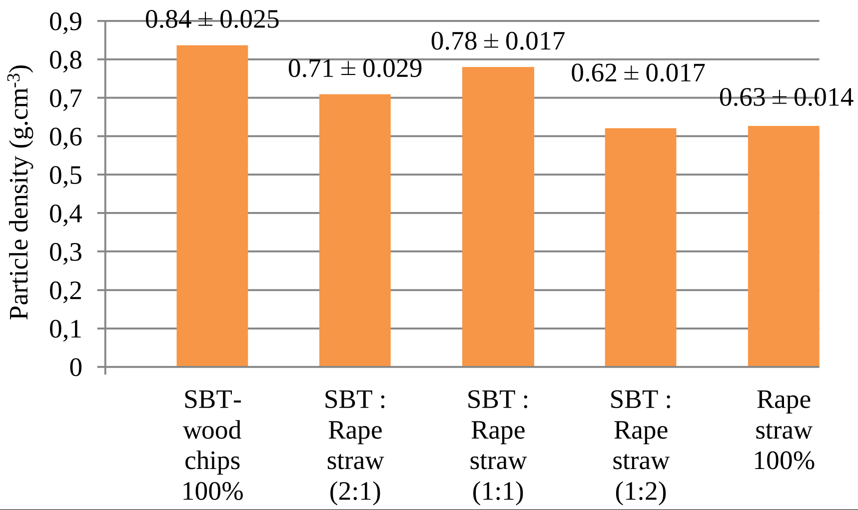


Figure 23.: Particle density of briquettes made from SBT wood and rape straw

5.3.6. Net calorific value

Net calorific value (NCV) affected by moisture content of raw material before briquetting is shown in the ***Figure 24***. The highest NCV from tested materials was obeserved in the SBT wood 17.31 MJ.kg^{-1} while the lowest NCV 15.0 MJ.kg^{-1} was measured in the wheat straw. Additivation of SBT wood to the wheat straw and rape straw briquettes has positive impact on their NCV, as shown in the ***Figure 25*** and ***Figure 26***. Both figures show that increasing ratio of SBT wood in wheat and rape straw briquettes increases their NCV. The most noticeable effect on NCV was found in the case of additivation of SBT wood to the wheat straw briquettes. By substitution of weighted half of wheat straw matter by SBT wood chips in the mixture SBT : Wheat straw (1:1) was reached increment of NCV by 1.16 MJ.kg^{-1} in comparison to the pure wheat straw briquettes. In the case of the mixture SBT : Rape straw (1:1) was reached increment of NCV by 0.72 MJ.kg^{-1} in comparison to the pure rape straw briquettes. Generally could be said that SBT wood improves properties of wheat and rape straw briquettes from the viewpoint of NCV which is important factor of solid biofuels in their utilization.

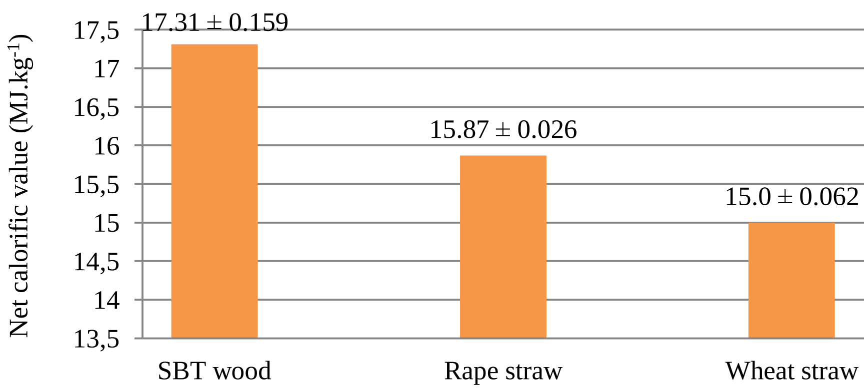


Figure 24.: Net calorific value of pure materials (MJ.kg^{-1})

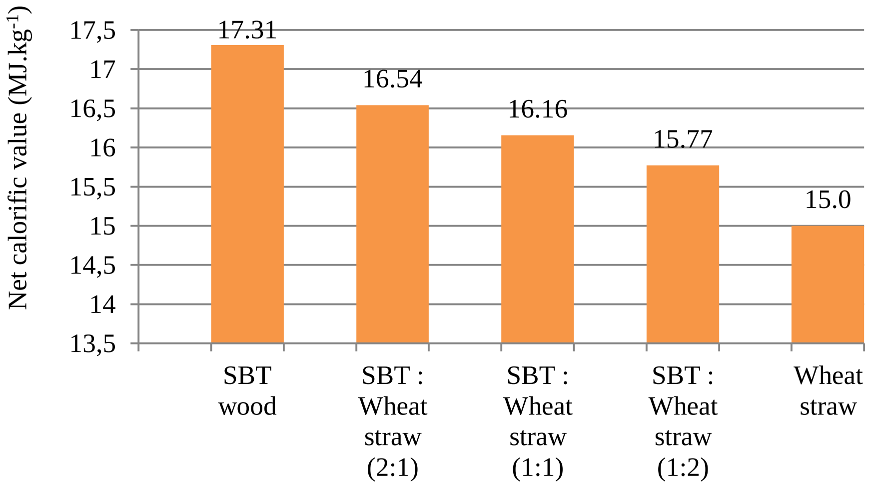


Figure 25.: Net calorific values of briquettes made from SBT wood and wheat straw (MJ.kg^{-1})

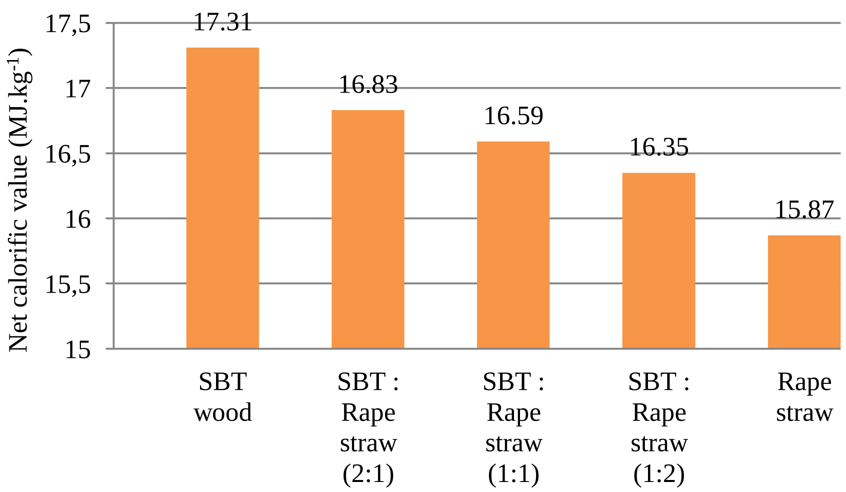


Figure 26.: Net calorific value of briquettes made from mixtures of SBT wood and rape straw (MJ.kg^{-1})

5.3.7. Mechanical durability

Durability of SBT wood briquettes was generally lower than durability of tested straw briquettes. The poorest results shown briquettes made from SBT wood grinded on the hammer mill which were about 20 % less durable than wheat straw briquettes, as shown in the ***Figure 27***. According to ČSN EN ISO 17225-1, only two mixtures and pure wheat straw briquettes fulfill the requirements of category DU95.0 with durability ≥ 95.0%, as shown in the ***Figure 28***. Addition of SBT wood to the rape straw showed similar trends as in the case of wheat straw briquettes and only three mixtures could meet the requirements of category DU90.0 with durability ≥ 90.0%, as shown in the ***Figure 29***. The effect of addition of SBT wood to the straw briquettes had generally decreasing tendencies on durability which is more or less related to the durability of briquettes produced from pure materials. Nevertheless, from the viewpoint of SBT wood briquettes, could be additivation of straw biomass helpful to improve durability properties of those briquettes.

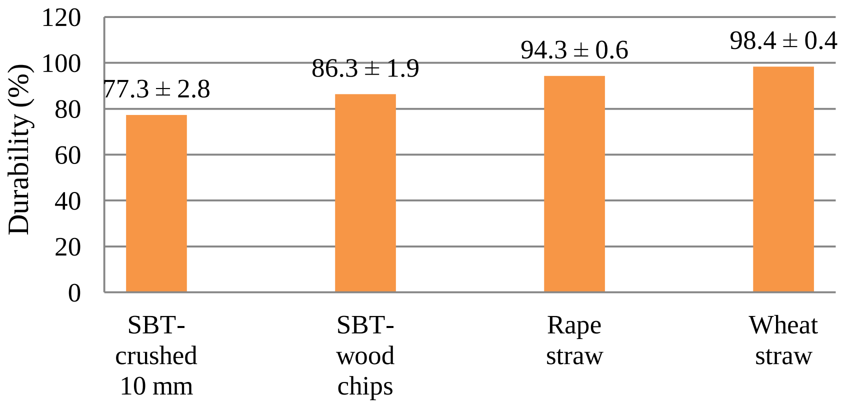


Figure 27.: Mechanical durability of briquettes made of SBT wood, wheat straw and rape straw

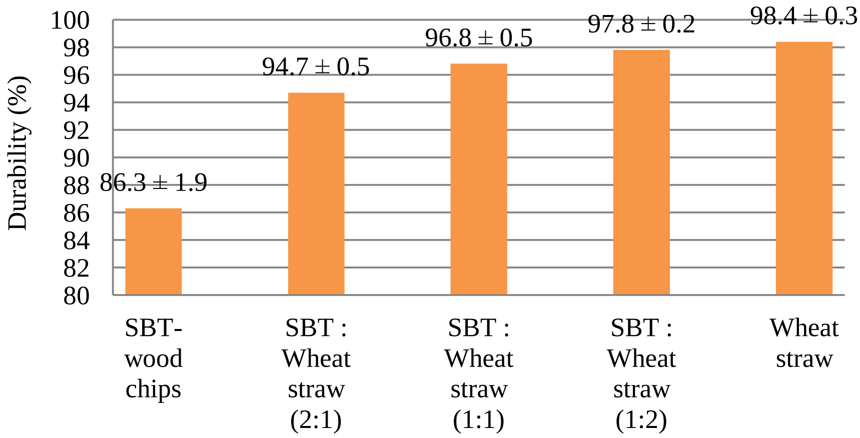


Figure 28.: Mechanical durability of briquettes made from SBT wood and wheat straw

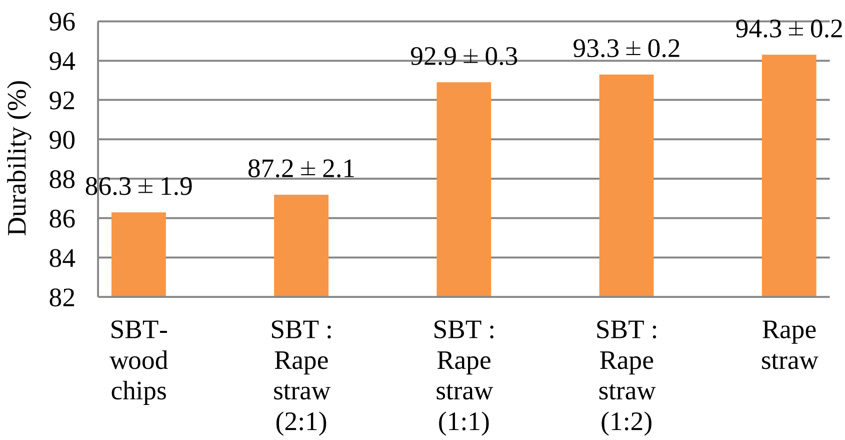


Figure 29.: Mechanical durability of briquettes made from SBT wood and rape straw

5.3.8. N, S , Cl content

The highest N contents were found in rape straw, while the lowest in wheat straw. S contents found in rape straw were the highest from observed. While the Cl contents were the lowest in the wood, the straw materials showed higher Cl contents. Calculated contents of N, S ,Cl in the pure materials and mixtures of SBT wood and straws are shown in the ***Table 20***, ***Table 21*** and ***Table 22***.

Table 20.: N, S, Cl content of pure materials wt. (%)

Material	N	S	Cl
SBT wood	0.72	0.68	0.09
Wheat straw	0.62	0.53	0.22
Rape straw	0.97	1.7	0.78

Table 21.: N, S, Cl content in combined briquettes of SBT wood and wheat straw

Material	N	S	Cl
SBT wood	0.72	0.68	0.09
SBT : Wheat straw (2:1)	0.49	0.63	0.14
SBT : Wheat straw (1:1)	0.67	0.61	0.16
SBT : Wheat straw (1:2)	0.65	0.58	0.18
Wheat straw	0.62	0.53	0.22

Table 22.: N, S, Cl content in combined briquettes of SBT wood and rape straw

Material	N	S	Cl
SBT wood	0.72	0.68	0.09
SBT : Rape straw (2:1)	0.80	1.05	0.32
SBT : Rape straw (1:1)	0.85	1.19	0.44
SBT : Rape straw (1:2)	0.89	1.38	0.55
Rape straw	0.97	1.7	0.78

IV. DISCUSSION

6.1. SBT wood yield

Determination of biomass yield was performed in 8-year old orchard in conditions of Czech Republic. For the first 3-5 years are plants left to grow without harvesting to build up the main trunk. After this period of growing begin harvesting which is done once in two years. According to Košek (2014) are yields more or less stable only with small annual increasment. Observed yield of wood was found to be on average 1.77 kg per tree (w.b.) which is 1,340.76 kg.ha^{-1}.yr^{-1} (w.b.) and 965.36 kg.ha^{-1}.yr^{-1} (d.b.) in 8-year old orchard in conditions of Czech Republic.

According to Stobdan et al. (2013) is 6-year old SBT plantation able to produce 18 tons of firewood in the conditions of Himalayas. However, this claim is based on preposition that plantation is used only for production of firewood and after this period is completely stumped and harvested. Rongsen (1992) reported greater accumulation of biomass in the conditions of Loess plateau, China. 15-year old SBT forest accumulated almost 2 tons of fresh biomass per year which is higher than other shrub species of the same age, such as *Caragana korshinskii* or *Rosa xanthina*. However, cultivation of SBT only for energy use looks non-profitable in todays world. Especially in comparison with perennial energy plants, such as willow (*Salix viminalis L.*) or miscanthus (*Miscanthus × giganteus*), are biomass yields of SBT insignificant. According to Stolarski (2013b) can short rotation coppice willow yield 14.1 t.ha^{-1}.yr^{-1} (d.b.) of biomass in conditions of Poland which is approximately fourteen times more than the yield of SBT plantation in conditions of Czech Republic. During the testing of yield responses on fertillizing of miscanthus in conditions of Great Britain, were found maximum yields of dry matter about 17 t.ha^{-1}.yr^{-1} which is more than seventeen times more (Shield et al., 2014). Since the SBT wood arises as a by-product within berries production, the yields of biomass will be always lower in comparison with energy crops.

The energy potential and properties of pruning residues produced within fruit orchards, vineyards or olive trees were investigated by many authors (Brkić et al., 2012; Grella et al., 2013; Dyjakon et al., 2014; Rosúa and Pasadas, 2012; Velázquez-Martí et al., 2011a; Cavalaglio and Cotana, 2007; Spinelli et al., 2010). Biomass yields vary according to species, region or cultivation practices. Pruning residues yields can vary according to the region, where are grown. Differences are given by different climatic conditions, agriculture practices and by different varieties grown in these regions. Therefore is comparison between regions difficult. However, great variation of biomass yields within different SBT orchards could be expected, as well as within other fruits.

Bilandzija et al. (2012) studied energy potential of pruned biomass within fruit production in Croatia. Highest measured yields per tree were found in the olive trees and plums which yield on average 9.08 kg per tree and 7.34 kg per tree, respectively. The lowest average biomass yield was reported in the grapevines which yield only 0.89 kg per vine. SBT trees give on average yield 1.77 kg per tree which is almost twice more than grapevines. However, after calculating yields per hectare was found that average biomass yield in the vineyards is twice higher than yield in plum orchards and relatively higher than in olive groves. While vineyards produced on average 4.3 $t.ha^{-1}$ of biomass, the yields in olive groves and plum orchards were found to be 2.5 $t.ha^{-1}$ and 2.1 $t.ha^{-1}$, respectively. Calculation of yield per hectare is affected by number of pruned plants which is given by different spacing of plants. Since SBT requires larger spacing 1.5 × 4 m and also ratio of non-harvested male plants within orchard, on hectare of orchard is harvested approximately 1,515 plants. While in the vineyards with spacing 1.9 × 1.1 m can be planted 4,781 of vines per hectare.

Since the utilization of pruning residues is related to cultivation of perennial plants, the effect of age plays significant role from the viewpoint of biomass accumulation. Velázquez-Martí et al. (2011b) found that within cultivation of grapevines for fresh fruits, vines younger than 10 years produce more biomass than older one. This fact is in contrast to the plants grown for vine production where older plants produced more biomass than younger one. Most of the fruit trees are in the first years left to grow without harvesting. Within the grapevines can this period last for 3 years, in the SBT orchards can this time reach even 5 years. This practice is necessary for establishment of solid trunk which will serve as a base for fruiting branches in the next years. Therefore can be expected lower biomass yields in early stage after establishment and their increasing during the next years.

The effect of pruning system within the same species is crucial for the amount of produced biomass which has to be periodically cut off. Within the apple production in Italy can these differences reach even 2.5 $t.ha^{-1}$ (d.b.), as reported in Grella et al. (2013). While for traditional pruning systems was in average produced 3.04 $t.ha^{-1}$ (d.b.) of branches, the *taille longue* technique generates only 0.46 $t.ha^{-1}$ within varieties *Ambrosia, Gala, Golden and Scarlett*. In comparison with yields of SBT, *taille longue* pruning system generates half as much of biomass. The yields of biomass within the vineyards are generally higher than in the SBT orchard. Velázquez-Martí et al. (2011b) measured biomass yields obtained by pruning of variety *Italia* grown for the fresh fruits production on Spanish Mediterranean coastal area. The effect of different vine training systems gives differences between biomass yields about 2 $t.ha^{-1}$. In the case of horizontal trellis system were observed yields about 5 $t.ha^{-1}$ (d.b.) and for standard trellis system only about 2.9 $t.ha^{-1}$ (d.b.).

Found biomass yield is lower than was expected in the beginning of research. However, within the SBT cultivation can be this biomass helpful from the viewpoint of local energy utilization. Moreover, utilization of SBT residual wood could provide valuable fuel for regions suffering by lack of fuelwood or located in the conditions where other plants are not productive. These regions are often located in developing countries, where biomass is the main source of fuel. Since the majority of SBT plantations is cultivated in China, Mongolia, India and Russia (Ni, 2013) could be further research of wood yields and SBT cultivation in these regions useful from the viewpoint of local energy utilization.

6.2. SBT wood briquettes properties

Produced briquettes were tested according to specifications given by international standard for Graded wood briquettes ISO 17225-3:2014(E). The comparison of tested specifications and specifications given by standard are shown in the ***Table 23***. SBT wood briquettes were made from wood chips originated from residual wood after harvest of berries. The wood with berries was frozen to ensure easy separation of berries from branches. However, no chemical substances were used in this process, and therefore can be their origin and source classified as a chemically untreated wood residues.

The **diameter** of briquettes is more or less given by diameter of die which was 65 mm in this case. Slight expansion was observed during measuring and final briquettes have diameter about 2 mm larger. This trend was similar to what was observed by Brožek et al. (2012). While briquettes made from wood shavings expanded only slightly, the briquettes made from birch wood chips expanded significantly more. The **length** of briquettes made from wood chips was on average 49.9 mm. For comparison of particle size effect on mechanical properties were made briquettes from the same material but crushed on hammer mill with 10 mm sieve. These briquettes show different length dimensions than briquettes made from chips. Briquettes made from crushed wood chips were about 8 mm longer with the length of 57.8 mm. According to Brožek et al. (2012) the briquetting press works so that at each piston working stroke the different material amount gets in the press chamber. This fact determines the length of briquettes because finer crushed material is better feed to the chamber than coarse one. The cylindrical shape of briquettes was given by the shape of matrix.

Generally is recommended that feedstock material for briquetting should have **moisture content** below 15 %. Since the initial moisture content of raw material was 29 %, the chipped material was dried to decrease MC below 15 %. Final feedstock material had MC 14.5 % which was decreased after briquetting to 13.6 %. Kers et al. (2010) found that optimum MC of material for briquetting should be between 10-18 %. This is crucial from the viewpoint of density and net calorific value of briquettes. MC below 10% or above 18 % cause that briquette particles are not consistent and briquette is falling to pieces. Highest density of tested briquettes was found in the material of 15 % MC.

Ash content of SBT wood briquettes was found to be 0.48 % which is in accordance with standard ISO 17225-3:2014(E). Since SBT wood chips contain wood and bark, the ash content analysis was affected by this fact. Vassilev et al. (2010) examined different parts of biomass and found that bark contained higher amount of ash than wood. While pine bark contains 1.8 % of ash, the sawdust from wood processing factory contained only 0.1 % of ash. Similar results showed spruce bark and wood which contained 2.9 % and 0.5 % of ash, respectively. SBT wood chips contained relatively high amount of bark which normally contains higher percentage of ash. Stolarski et al. (2013a) found that ash content of willow is 1.61 % which is more than triple of SBT wood chips and therefore could be stated that ash content is in comparison with other materials relatively low.

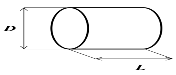
The **particle density** of briquettes did not meet the requirements of standard. Whereas MC was in the time of briquetting optimal, the particle density was 0.837 $g.cm^{-3}$. Li and Liu (2000) observed density and mechanical resistance of briquettes made from different types of oak wood biomass (sawdust, wood mulch, bark mulch, chips). From tested materials, only briquettes made from oak chips had particle density below 0.9 $g.cm^{-3}$ and during the mechanical durability testing were broken to the pieces. It was concluded that rather than chips material is better to process wood to mulch or sawdust which show greater mechanical properties of briquettes. of SBT was found to be 17.2 $MJ.kg^{-1}$ with MC of 14.5 %. This value is within the range of other pruning residues, as stated in Bilandzija et al. (2012). The highest average NCV was found in peach and nectarine wood residues which have NCV 17.7 MJ.kg^{-1}, while the lowest was from fig residue which was 15.6 MJ.kg^{-1}. However, measured NCVs by Bilandzija et al. (2012) were calculated with MC below 9 % which probably affect the final NCV. For briquetting could be MC below 10 % critical, and therefore were MC of 14.5 % considered as an optimal for this purpose. In Rongsen (1992) is stated that SBT wood is valued in Himalaya mountains for its higher heating value which is about 20 MJ.kg^{-1}. Based on this study can not be this statement approved because even the gross calorific value did not reach 20 MJ.kg^{-1}. Based on results was SBT wood briquettes classed as briquettes with NCV higher than 15.5 MJ.kg^{-1}.

Content of N, S and Cl was found to be 0.72 %, 0.68 % and 0.09 %, respectively. The effect of content N and S elements in the fuel is crucial from the viewpoint of emissions which are released during combustion. Cl content is important for metal parts of combusting equipment which are exposed to corrosive effect. Cl content exceeds standard limitations (Cl $\leq$ 0.03) almost three times. N content in SBT wood is comparable with other pruning residues according to Bilandzija et al. (2012). In Croatia was highest N content found in Fig residues 1.05 %, while the lowest was found in apricot prunings 0.54 %. However, according to observation made by Vassilev et al. (2010) is N content in SBT wood similar to the contents in barks or in mixed forest residues. Beech, elm and tamarack barks showed the highest N contents (0.7 %) from observed materials, as well as forest residues and olive wood.

Sulphur content in SBT wood was higher than in the most of biomass sources according to Bilandzija et al. (2012) and Vassilev et al. (2010). According to Hein and Bemtgen (1998) is advantageous co-combustion of biomass and coal in electric power plants because of lower SO_2 emissions. Found sulphur content in wood, straw and energy crops were usually below 0.15 % of the dry material. Coal contains usually up to 3 % of sulphur in dependency on type of coal. While anthracite coal contains usually below 1 % of sulphur, the brown coal mined in Assam, India shows on average 4.3 % content of sulphur (Murkherjee and Borthakur, 2001). According to Haneklaus et al. (2003) is sulphur accumulated in the tissues of plants when its supply is abundant in the soil or when the protein synthesis is restricted by deficiency of nitrogen. In the leafy biomass can S content reach 0.8 % while in the wood should not exceed 0.1 %. However, found concentration in SBT wood is obviously higher than limitations given by standard (S $\leq$ 0.05) and therefore is further research of this phenomenon recommended.

All of studied **minor elements** were in the limits given by standard. Therefore, could be SBT wood safely used as a biofuel in common combustion facilities. Moreover, are minor elements of special importance for particulate emissions produced during combustion, as well as content of these emissions in the ashes which are used as a fertilizer (Baernthaller et al., 2006). According Kotlánová (2010) are sources of minor elements in the biomass mostly related to the way of treating or manipulation of this material. As a main sources of contamination in biomass could be considered conservation chemicals (As, Zn, Cr, Cu), colour coatings (Pb, Cd), using of mineral oils or lubricants and used equipment or devices for processing (Fe, Cr, Ni). However, in the case of SBT wood could be considered only contamination by harvesting equipment which was not found as problematic from the viewpoint of minor element content as shown in ***Table 23***.

Table 23.: Properties of SBT wood briquettes evaluated according to ISO 17225-3:2014(E)

Property class	Units	Results	Limitations	Evaluation
Origin and source		Chemically untreated wood residues	none	fulfilled
Dimensions and shape	mm	67.08 (*D*), 49.92 (*L*)	none	fulfilled
	Shape		none	fulfilled
Moisture	w-% a.r.	14.5	M ≤ 15	fulfilled
Ash	w-% dry	0.48	A ≤ 3.0	fulfilled
Particle density	g.cm^{-3}	0.837	DE ≥ 0.9	unfulfilled
Net calorific value	MJ.kg^{-1}	17.2	Q ≥ 14.9	fulfilled
Nitrogen	w-% dry	0.72	N ≤ 1.0	fulfilled
Sulphur	w-% dry	0.68	S ≤ 0.05	unfulfilled
Chlorine	w-% dry	0.09	Cl ≤ 0.02	unfulfilled
Arsenic	mg. kg^{-1} dry	0.024	As ≤ 1	fulfilled
Cadmium	mg. kg^{-1} dry	0.038	Cd ≤ 0.5	fulfilled
Chromium	mg. kg^{-1} dry	0.503	Cr ≤ 10	fulfilled
Copper	mg. kg^{-1} dry	3.171	Cu ≤ 10	fulfilled
Lead	mg. kg^{-1} dry	0.129	Pb ≤ 10	fulfilled
Mercury	mg. kg^{-1} dry	0.048	Hg ≤ 0.1	fulfilled
Nickel	mg. kg^{-1} dry	0.657	Ni ≤ 10	fulfilled
Zinc	mg. kg^{-1} dry	6.865	Zn ≤ 100	fulfilled

6.3. Combined briquettes properties

Because of lower yields of SBT wood were alternatively manufactured combined briquettes from mixtures of SBT wood and rape straw and SBT wood and wheat straw. In view of scarce resources of SBT residual wood in Czech Republic, could be its combination with abundant material, such as residual straw, advantageous. Moreover, residual straw has some negative properties when utilized in the form of briquettes, such as high ash content or higher content of Cl than other biomass. These problems could be compensated by mixing straw with other suitable biomass with better properties. Briquettes were made from different mixtures with various portions of SBT wood and its influence on briquette propertieswas observedand assessed according to standard ČSN EN ISO 17225-1, as shown in the ***Table 24*** and ***Table 25***.

Since the briquettes were made of mixtures of two different materials, they were classed to the category of homogenous mixtures and mixtures. According to Brožek et al. (2012) are dimension parameters, such as length or diameter, less important from the viewpoint of fuel quality. However, influence of different materials on length of briquettes was obvious. Generally can be stated that adding of SBT wood chips to the straw materials has influenced their dimensional stability due to different characteristics of materials.

Moisture content of combined briquettes was affected by MC of feedstock materials and by conditions of briquetting and subsequent storage. The final briquettes had lower MC than raw material before briquetting. This fact could be caused by higher temperatures in briquetting chamber or by storage conditions. Moisture content were varying between 11.44 % at rape straw briquettes, up to 13.62 % at SBT wood briquettes. Both straw materials were having lower MC than SBT wood and therofore with increasing percentage of SBT wood in the briquettes, were MC increased. Therefore could be stated that by adding SBT wood MC properties of combined briquettes were worsened.

The ash and N, S, Cl contents as well as NCV, are related to the properties of raw materials and their proportions in the mixtures. The ash content is generally higher in the herbaceous biomass than in the wood. By adding of SBT wood to the straw briquettes in proportion 1:1, the ash content was significantly lowered to the level that both mixtures could be classed as A5.0 (A $\leq$ 5 %) according to ČSN EN ISO 17225-1. These values were comparable to those observed by Hutla (2010), when briquettes made from mixture of perennial grasses and poplar in weighted ratio 1:1, had ash contents 4.62 % and briquettes made from mixture of perennial grasses and spruce bark in the same ratio had ash contents

4.27 %. N and S contents were higher in SBT wood than in wheat straw, therefore briquettes made from these mixtures were deteriorated by adding of SBT wood. This is in contrast to briquettes made from mixtures of SBT wood and rape straw because of higher N and S content in the rape straw. The Cl contents in SBT wood were lower than in straws and therefore were mixtures from viewpoint improved by adding SBT. NCV was increased by adding of SBT which was given by calorific values of pure materials and their proportions in the mixtures.

Particle density of briquettes is given by material properties and their behaviour during briquetting. It was predicted that straw materials will have lower particle density than wood. However, results showed that particle density is more or less given by ability of material to be compressed and stick together. According to Plíštil (2004) is from the viewpoint of density crucial compression pressure in the die of piston which affects final density of briquettes. For different materials should be used different pressures to ensure proper compaction of particles. In this study were all mixtures briquetted under the same pressures and on the same briquetting machine. According to Križan and Matúš (2012) is density of briquettes affected by briquetting temperatures, pressures and MC of briquetted material. The lowest particle density was found in rape straw briquettes (0.627 $g.cm^{-3}$) and highest one in wheat straw briquettes (0.903 $g.cm^{-3}$). These properties affected density of combined briquettes with SBT wood which were within the range of marginal densities for pure briquettes. Hutla and Jevič (2012) studied densities of pure and combined briquettes made of fescue grass and poplar chips. By mixing of these two materials in ratio 1:1 were produced briquettes of higher density about 0.08 $g. cm^{-3}$. Tumuluru et al. (2015) found that effect of storage time has crucial effect on briquette densities because particle density of wheat straw briquettes decreased during two weeks of storage by 0.05 $g.cm^{-3}$. While all combined briquettes made of wheat straw and SBT wood passed the minimum given particle densities by standard (DE $\geq$ 0.8 $g.cm^{-3}$), the combined briquettes made of rape straw and SBT wood did not met given requirements of standard. It can be summarized that while adding of SBT to rape straw briquettes increases their density, adding of SBT to wheat straw briquettes decrease particle density and therefore deteriorate their mechanical properties.

Overall durability of combined briquettes is more or less related to the durability of briquettes from pure materials where the lowest one was found in SBT briquettes (86.3 %) and the highest one in wheat straw briquettes (98.4 %). In the case of combination of SBT wood and wheat straw can be ratios of 1:1 and 1:2 (SBT : Wheat straw) considered as a suitable from the view point of durability. Their durability properties were not affected by addition of SBT wood so much, because their durability did not decrease below level of 95 % and could be classed to the category DU.95. Lower durability was observed in combination of SBT wood and rape straw. Similarly, previous mixtures were ratios of 1:1 and 1:2 (SBT : Rape straw) enough durable to fulfil the limitations of category DU.90 for durability higher than 90 %. Ivanova et al. (2014) researched durability in briquettes made from *Miscanthus* × *giganteus*, *Miscatnhus sinensis* and sawdust. While briquettes made from Miscanthus had durability below 90 %, the combination in ratios 1:1 with sawdust improved their durability over 90 %. In this study were used SBT wood chips which in the case of wheat straw and rape straw decrease durability. At the cost of decreased durability can be SBT wood chips helpful in improving other fuel properties of briquettes.

Table 24.: Effect of adding SBT wood chips on quality of wheat straw briquettes

Parameter	Effect on parameter	Effect on briquette quality
Dimensions and shape	none	no impact
Moisture content	increased	worsened
Ash content	decreased	improved
Particle density	decreased	worsened
Net calorific value	increased	improved
Mechanical durability	decreased	worsened
Nitrogen content	increased	worsened
Sulphur content	increased	worsened
Chlorine content	decreased	improved

Table 25.: Effect of adding SBT wood chips on quality of rape straw briquettes

Parameter	Effect on parameter	Effect on briquette quality
Dimensions and shape	none	no impact
Moisture content	increased	worsened
Ash content	decreased	improved
Particle density	increased	improved
Net calorific value	increased	improved
Mechanical durability	decreased	worsened
Nitrogen content	decreased	improved
Sulphur content	decreased	improved
Chlorine content	decreased	improved

VI. CONCLUSION

6.1. Conclusions

- On the basis of experimentally estimated yield of residual wood from SBT orchard and analysis of literature references, the amount of residual biomass was assessed as a less significant from the viewpoint of broader energy use. However, the local energy utilization of this biomass can be sufficient and could be used as fuelwood for heating or cooking. In comparison with biomass yields of other fruit species the SBT wood yields were found to be lower. Moreover, cultivated areas of SBT in Czech Republic are incomparable with other fruit species. Nevertheless, the biggest producers of berries are usually developing countries, such as China, Russia, Mongolia or India, where the cultivated areas could produce much higher biomass quantities. In rural areas is energy utilization of biomass still one of the main energy resources and therefore could SBT residual wood provide significant energy source for local people. The biomass yields in fruit orchards depend on species, region, agriculture practices or varieties of growing species. Therefore different yields under specific conditions can be expected also in cultivation of SBT.
- Based on the measurements of briquette parameters made from SBT wood chips and their comparison with international standard, the first hypothesis was rejected. It can be concluded that SBT wood briquettes did not have sufficient properties to meet requirements of standard for Graded wood briquettes ISO 17225-3:2014(E). SBT briquettes did not fulfill standard specifications of particle density, sulphur and chlorine contents. Particle density could be improved by using different types of pressing equipment with different working pressures which also affects temperature in pressing chamber necessary for appropriate binding of particles. Moreover, the particle density could be improved by different fractions of feedstock material. Chlorine contents in wood was found to be slightly over limit of standard specifications. This parameter is given by local conditions in which are plants cultivated. The important parameter from the viewpoint of emissions is sulphur content which was found higher than maximum given by standard. Also in comparison with other plants were S contents higher. Higher S contents in the plant tissues could be caused by abundance of S in the soil or by deficiency of nitrogen available for plant.

- Due to observed lower yield in SBT orchard, the mixtures for production of combined briquettes were prepared with other sources of abundant biomass, such as residual wheat and rape straw. Based on the measurements of briquette parameters and their comparison with technical standard ČSN EN ISO 17225-1 was second hypotheses rejected for both combinations of materials. In the case of briquettes made of SBT wood and wheat straw was majority of measured parameters worsened by addition of SBT wood in the mixture. Most of the worsened parameters were given by characteristics of combined materials and amount of these materials in the mixture. While characteristics, such as particle density or mechanical durability can be technologically improved, the contents of nitrogen and sulphur are given by character of material. Worsening of MC by addition of SBT wood in briquettes was given by higher MC in the wood, however this parameter could be improve by additional drying. Addition of SBT wood to the rape straw briquettes showed that majority of parameters was improved. However, mainly mechanical durability was worsened.

6.2. Recommendations

- Based on the above discussion, further research of wood yields and SBT cultivation in other regions could be beneficial from the viewpoint of local energy utilization. The yields could be different in other regions and therefore their energy importance could be much higher.
- The briquettes made of SBT wood could be well used as a source of energy for heating or cooking. From the viewpoint of handling and storage the briquettes can solve problems linked to the utilization of whole tree branches or wood chips. For improvement of the above problematic parameters further research of briquetting conditions on physical and mechanical properties and effect of soil conditions on element content in the wood is recommended.
- The combined briquettes of SBT wood and residual straw shows possible utilization of locally available material and material which is abundant. The important fuel parameters, such as net calorific value and ash contents, were largely improved by increasing proportion of SBT wood in the briquettes. However, mechanical properties, such as particle density and mechanical durability were

mostly worsened. For further research would be benefitial to investigate influence of briquetting conditions (type of pressing equipment, working pressure, feedstock input fractions) on quality of briquettes.

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