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Storage Problems of Poplar Chips from Short Rotation Plantations with Special Emphasis on Fungal Development

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Abstract – There are several problems in storing wood chips freshly harvested from short rotation plantations, which result in quality losses as well as in dry matter and energy losses. The factors influencing the degradation of raw material are examined in this paper with special focus on fungal development. An excessive growth of fungi is connected to dry matter losses and also to an increased health risk during raw material handling.

The following factors were measured during 6 months storage of poplar wood chips depending on particle size: box temperature, moisture content, pH-value, appearance of fungi in the storage and the concentration of fungal particles in the air. The results show a close connection between particle size, temperature and attack of fungi. During the storage mesophilic and termophilic species of the genera *Alternaria, Aspergillus, Cladosporium, Mucor* and *Penicillium* appeared. The concentration of fungal particles is the highest for fine chips and decreases in bigger particles. There was a special focus on the investigation of the properties of coarse chips (G 50), which represent a good compromise between handling, storage losses and health risk due to fungal development.

wood chips / poplar / storage / temperature / fungi

Kivonat – Rövid vágásfordulójú nyár apríték tárolási problémái, különös tekintettel a kifejlődő gombákra. Frissen kitermelt rövid vágásfordulójú fafajokból előállított apríték tárolása során számos probléma merül fel, melyek eredménye minőség-, szárazanyag- és energiaveszteség. Ebben a tanulmányban a nyersanyag-degradációt befolyásoló tényezők kerültek vizsgálatra, különös tekintettel a kifejlődő gombákra. Ezek rendkívüli elszaporodásának köszönhető a szárazanyag-veszteség mellett a nyersanyag kezelése során fellépő, megnövekedett egészségügyi kockázat is.

Nyár faapríték hat hónapos tárolása folyamán az aprítékméret függvényében a következő tényezők mérése zajlott: a tárolón belüli hőmérséklet, nedvességtartalom, pH, a tárolóban megjelenő gombák és azok száma a levegőben. Az eredmények szoros összefüggést mutatnak, különösen az aprítékméret, a hőmérséklet és a gombák száma közt. A tárolás során mezofil és termofil gombák fejlődtek. A következő nemzetségekhez tartozó fajok voltak megfigyelhetők: *Alternaria, Aspergillus, Cladosporium, Mucor, Penicillium.* A gombák száma a finom aprítéknál volt a legmagasabb, ami az aprítékméret növekedésével csökkent. A kutatás folyamán különös szerepet kapott a középfinom apríték tulajdonságainak vizsgálata (G 50), mely kompromisszumos megoldást jelent a kezelés, tárolási veszteségek és a kifejlődő gombáknak köszönhető egészségügyi kockázatok között.

faapríték / nyár / tárolás / hőmérséklet / gomba

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1 INTRODUCTION

The demand for wood chips from short rotation crops (SRC) such as poplar and willow for bioenergy has increased in recent years due to annually increasing total energy consumption and high prices for fossil resources. SRC chips have several advantages such as harvesting in winter, low fertilisation and maintenance needs, but some disadvantages as well (Jirjis 1995, Scholz et al. 2004, 2009). Storage at high moisture content influences the quality and storage losses of wood. Several factors have effects on storage processes. Many studies have shown that the biggest influencing factors are particle size, height of pile, air permeability and rain protection (Jirjis 2005, Scholz et al. 2005, Scholz – Idler 2005). Temperature development and moisture content in the storage pile, dry matter loss, quantity of fungal particles[1] in the air vary depending on the layout of the storage (Scholz – Idler 2001, Idler et al. 2004). The aim of this work was to determine the influence of the particle size on storage of poplar chips, to identify optimal forms of raw material preparation and storage design for minimum energy loss and health risks for operators. We also wanted to find an optimal length of chips, where the quality and mass losses are not as high as in common fine chips (G 30), but which are still easy usable for medium sized heating systems. Earlier studies have shown that the minimum energy loss and the lowest health risks for operators were reached by storing wood as chunks instead of chips (Scholz-Idler 2005, 2007). But chunks have to be comminuted before they can be burned and they are difficult to handle. Therefore, this study was done with special focus on coarse chips, which are still easy to handle and probably ensure lower mass losses during storage and reduced health risks than fine chips.

2 MATERIALS AND METHODS

The raw material used for this investigation was harvested from an 18 year old SRC plantation of poplar (Japan 105, 2 year rotation cycle) at the Leibniz Institute for Agricultural Engineering Potsdam-Bornim (ATB, Germany) in January 2012. The harvested material was chopped to different lengths immediately after they were felled and before storage. Three different particle sizes were produced and classified according to ÖNORM M 7133 for storage tests: fine chips G 30 (tractor mounted disk chipper FARMI CH150), coarse chips G 50 (tractor mounted ATB mower-chipper), and chunks G 100 (Chunk chopper DIEMER). The chips and chunks where stored immediately after harvest and prepared in separate rectangular boxes 2.5 m high and 2.0 m wide (V=10 m^3) with thermally insulated sides and rain-protection at the ATB (*Figure 1*).

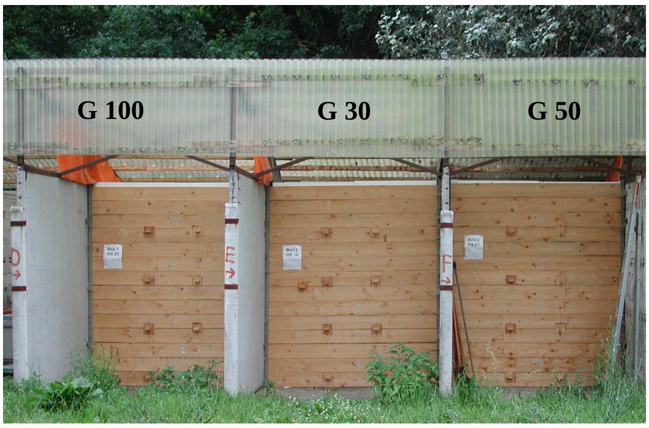

Figure 1. Storage boxes for poplar chips and chunks of different length (G 100, G 30 and G 50)

[1] hyphae, infested wood particles, spores

During the storage, the temperature (outside and inside of the boxes), humidity, moisture content, pH, wind speed, fungi on the wood and concentration of fungal particles in the air were measured and analysed for a storage period of 6 months (11th January 2012 – 31st July 2012).

The temperature inside of the box was measured at different heights (*Figure 2*) by an electronic pick thermometer. Ambient temperature and data outside the box were provided by the weather station of ATB.

The temperature measurements until 12th March showed a bigger fluctuation because of manual measuring. After this date an automatic measuring system was installed and air ventilation influences on the measurements have been avoided.

The moisture content, pH and the concentration of fungal particles were measured on sampling days. At the beginning of the experiments, samples were taken every two weeks after the second month of storage samples were taken only every month because many studies show that after two months the values do not change rapidly (Scholz – Idler 2001, Idler – Scholz 2001). Due to the weather conditions, measuring was not always possible. Therefore, in some cases fungi were not countable in the samples.

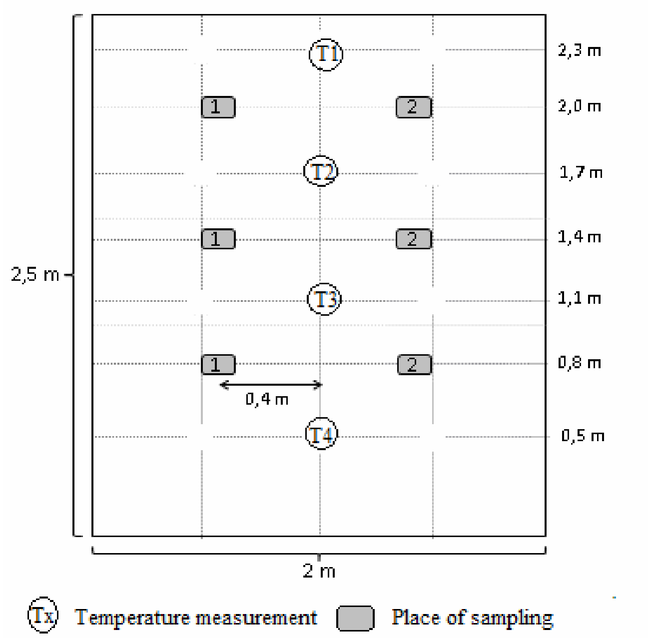

Figure 2. Design of boxes for measuring and sampling

Samples for the determination of moisture content and quality of the wood chips were taken from six different places per box (*Figure 2*). They were measured on a digital scale for moisture analysis immediately after sampling and were dried at 105 °C to constant weight. The moisture content was calculated from measured dry matter content. Wind speed was measured by a cup anemometer (Ahlborn, Germany).

Samples were processed to analyse pH and fungi. The pH was measured by a pH-electrode Sen Tix 41 with temperature compensation (WTW, Weilheim, Germany). The concentration of fungal particles was determined using the spread plate method. 20 g samples were shaken for 30 minutes with a rotary shaker at 180 rpm in 180 ml of Ringer solution (Merck, Darmstadt, Germany), which then was made into a decadic dilution series. An aliquot was put on special nutrient plate. Mesophilic fungi were measured by using substrate DG 18 (Oxoid, Darmstadt, Germany) and thermophilic fungi by using Malt Extract Agar (Merck, Darmstadt, Germany) with 0.01% chloramphenicol. Plates were incubated for five days at 20 °C and for two days at 37 °C. Then the number of the colonies that developed was counted and the concentration of fungal particles in a log colony forming units per g fresh mass (*lg cfu/g FM*) was calculated. The identification was made microscopically (Pitt 1991, Samson et al. 2000, Klich 2002). The concentration of fungal particles in the air was measured directly on the top of the boxes using the Airport sampler MD8 (Sartorius, Göttingen, Germany) and the MAS 100 eco (Merck, Darmstadt, Germany). The Airport sampler MD8 (sample volume: 1000 liters, flow rate: 50 l/min), using the gelatine membrane filter method, was applied at air relative humidity under 80%. Above this value MAS 100 eco was used (sample volume: 1000 liters, flow rate: 100 l/min) which is based on the impaction principle. The control samples were taken at a height of 1.50 m. The samples of Airport MD8 were dissolved in 10 ml warm (30 °C) sterile saline solution (0.9% NaCl + 0.01% Tween 80) and were shaken for 30 minutes with a rotary shaker at 180 rpm at 30 °C. Then a decadic dilution series was made. The identification and the counting of mesophilic and thermophilic fungi were done in the same way as for the examination of fungi on the wood samples. The measurement with MAS 100 eco is a direct method. For every sampling four nutrient plates were used, two DG 18 substrates for examination of mesophilic fungi and two malt extract agar ones with 0.01% chloramphenicol for identification of thermophilic fungi. Plates were incubated for five days at 20 °C and for two days at 37 °C.

3 RESULTS

3.1 Temperature

During the examination the air temperature and the temperature in the boxes were measured at four different levels because this factor shows a close connection with development of fungi. The measurements show characteristic differences in relation to the length of the wood chips (*Figure 3*). The temperatures are given as averages of all heights from T1 to T4 (*Figure 2*).

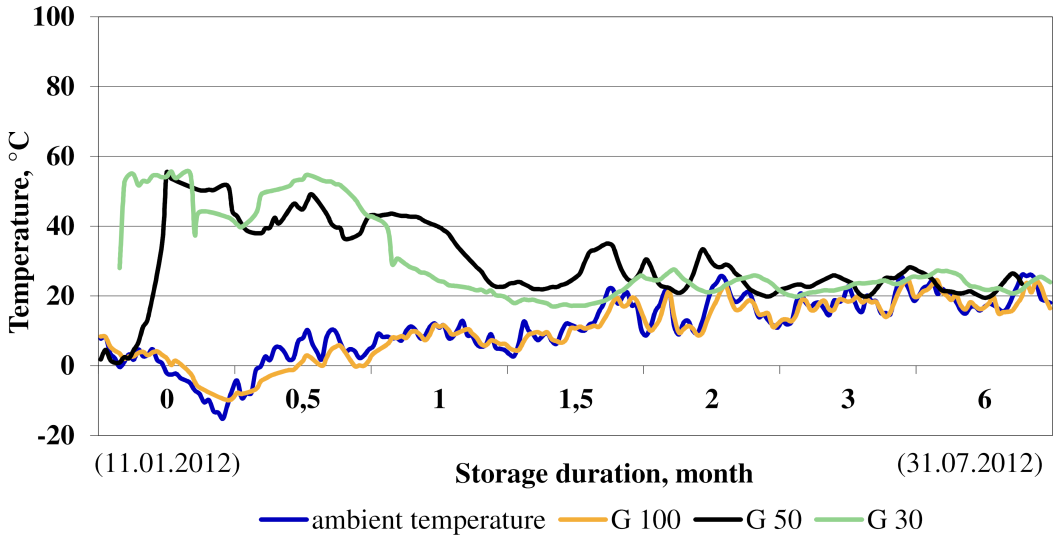

Figure 3. Development of average temperature (°C) in the storage boxes of wood chips of different size

Average temperatures in the box of chunks (G 100) showed a very close connection with ambient temperature. However average temperature in the box of fine (G 30) and coarse chips (G 50) rapidly increased in the first two weeks and reached their peaks at about 55 °C. Data started to drop off in the box of fine chips after storage two months and in the box of coarse chips after 10 weeks. The temperature decreased then to near to ambient temperature.

Temperatures in the box of chunks showed almost similar values at all levels. In the box of fine chips. the highest temperature was measured at the second level (T2) similar to coarse chips (*Figure 4*). In the box of coarse chips, the temperature increased rapidly in the first of two weeks of storage and reached its temperature peaks of about 60 °C. This began to decrease after 11 weeks. Approximately 4 weeks later, the temperature started to approach the ambient temperature.

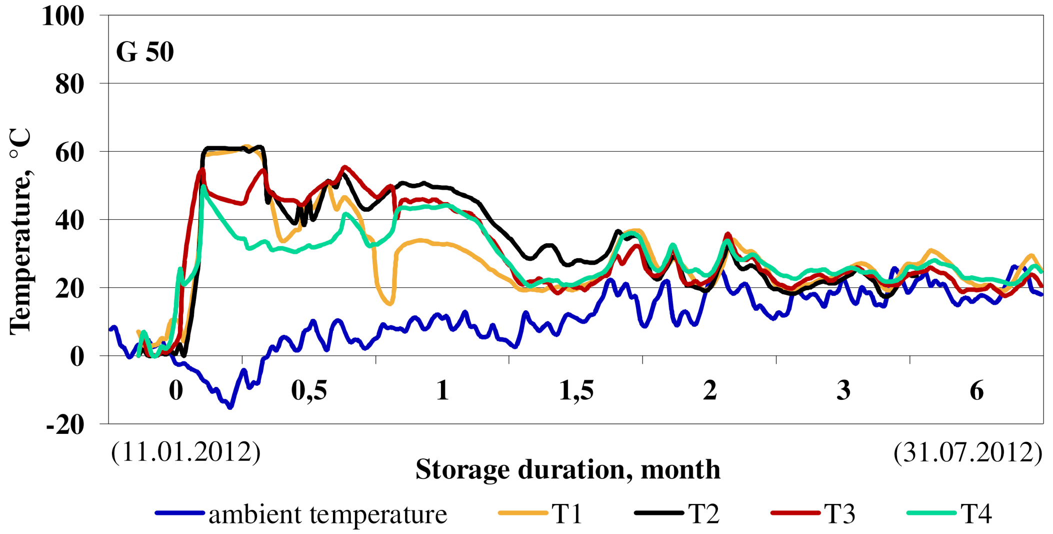

Figure 4. Development of temperature (°C) at different heights in coarse chip piles (G 50)

3.2 Moisture content, pH, fungi

In every box the same genera of fungi were found: mesophilic *Cladosporium ssp., Mucor ssp., Penicillium ssp.* and thermophilic *Aspergillus ssp.*

In the box of chunks (G 100), the number of mesophilic and thermophilic fungal particles rose after one month (*Figure 5*).

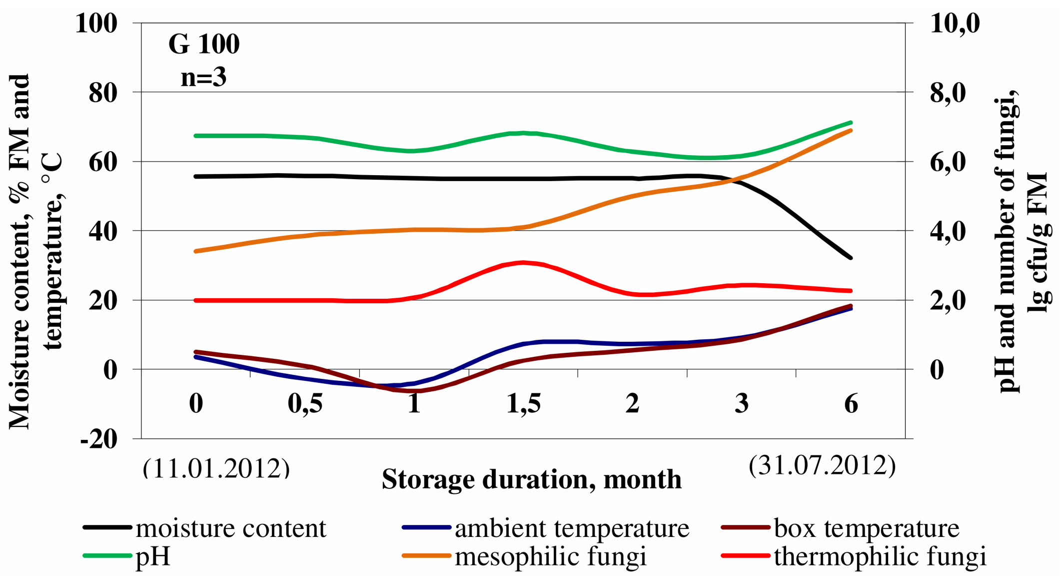

Figure 5. Average values of moisture content (%, fresh mass), pH, temperature (°C) and development of fungi (log colony forming units per g fresh mass) during the storage of chunks (G 100)

The quantity of mesophilic fungal particles in coarse chips (G 50) increased in one month and the order of magnitude did not change till the sixth month, while the concentration of particles with thermophilic fungi rose rapidly (*Figure 6*). This was the tendency until the third month and then it started to sink. The moisture content decreased after the second month.

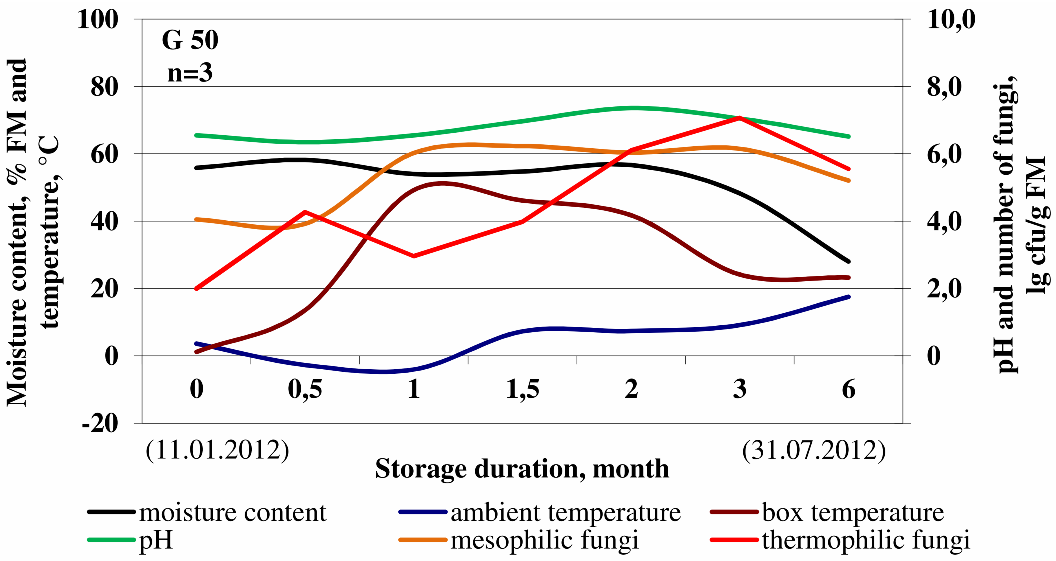

Figure 6. Average values of moisture content (%, fresh mass), pH, temperature (°C) and development of fungi (log colony forming units per g fresh mass) during the storage of coarse chips (G 50)

The number of mesophilic and thermophilic fungal particles in the fine chips (G 30) rose for half of a month and the order of magnitude did not change until the third month, when it started to drop (*Figure 7*). The moisture content was almost constant over the whole storage period of 6 months.

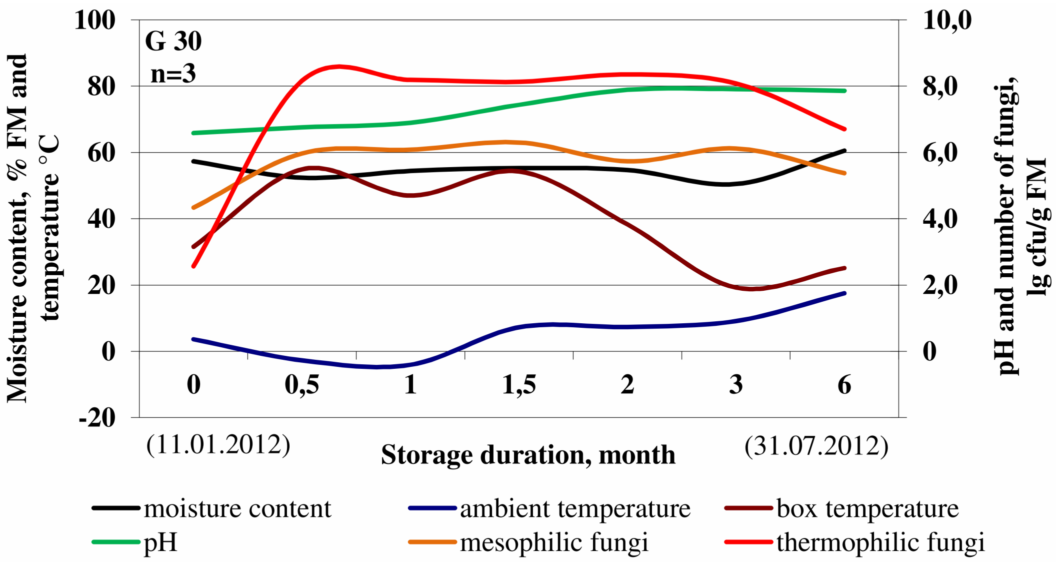

Figure 7. Average values of moisture content (%, fresh mass), pH, temperature (°C) and development of fungi (log colony forming units per g fresh mass) during the storage of fine chips (G 30)

In the storage box of chunks and coarse chips, the pH showed little fluctuation, but in fine chips the pH increased from 6.58 to 7.91 due to the excessive growth of fungi.

3.3 The concentration of fungal particles in the air

The number of mesophilic fungal particles in the air was always higher than that of thermophilic fungal particles, except in the fine chips (*Figure 8*).

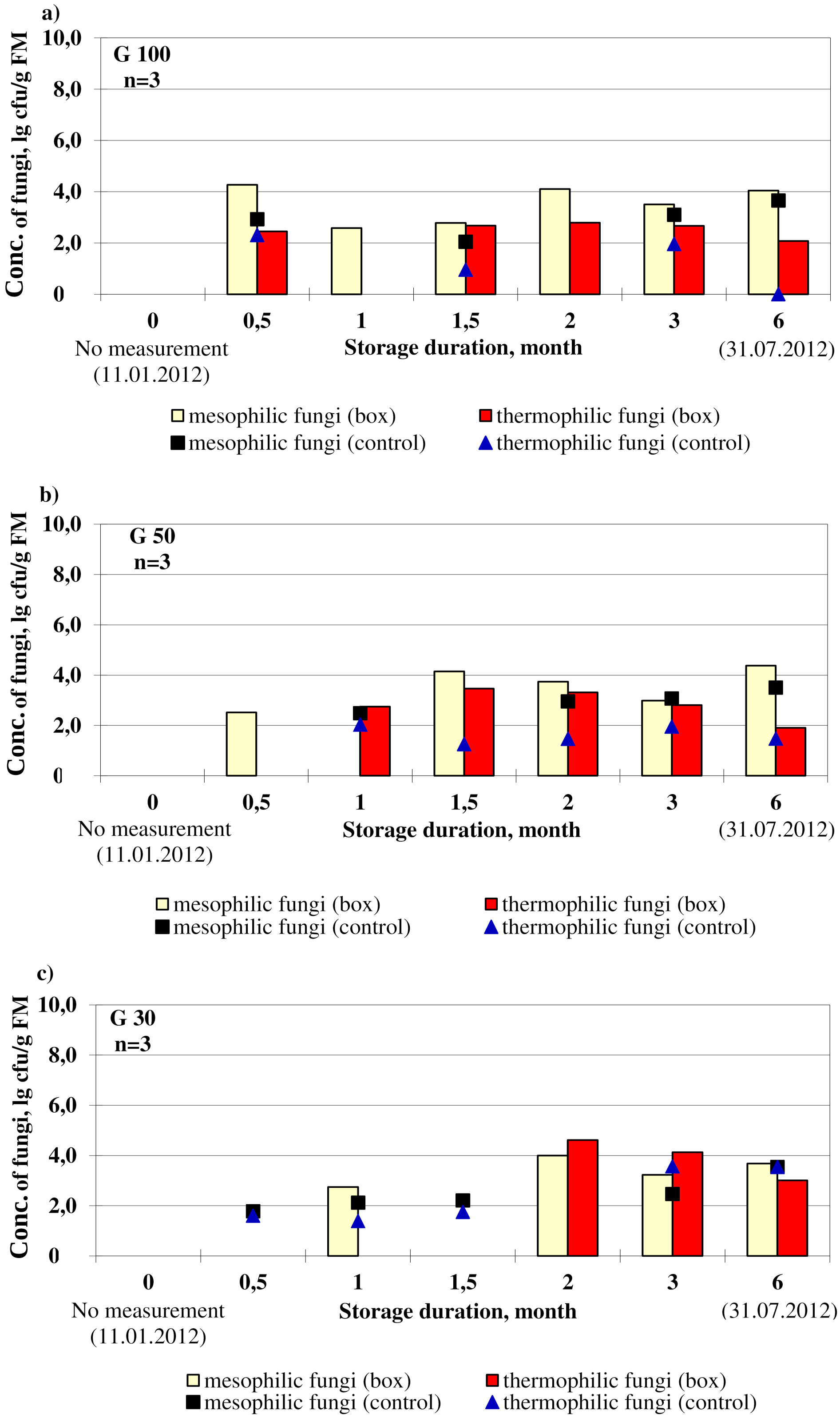

Figure 8. Concentration of mesophilic and thermophilic fungal particles (log colony forming units per m^3) in the air over the storage boxes of a) poplar chunks (G 100), b) coarse (G 50) and c) fine poplar chips (G 30)

The concentration of fungal particles in the air decreased with increasing distance. The number of mesophilic fungi was slightly higher on the top of the boxes than in the control samples and the order of magnitude was the same for all lengths of the wood chips. The number of thermophilic fungi increased until the second month of storage, and then it started to sink. Numbers grew with decreasing length of the wood chips.

The following genera of fungi were found: *Alternaria, Aspergillus, Cladosporium, Mucor* and *Penicillium*.

4 DISCUSSION AND CONCLUSIONS

Particle size is one of the most important influence factors in the storage of freshly harvested short rotation poplar in unventilated boxes. Temperatures in piles of coarse and fine chips can increase to nearly 60 °C during storage. The highest temperature was measured in fine chips. In every pile, the highest temperatures were recorded in the first period of storage; then the values start to decrease. The heating was due to the activity of microbes, residual respiration of wood cells and the restricted air flow within G 30 wood chip piles because of their lower bulk porosity. The temperatures in the box of chunks were lowest and corresponded to the ambient temperatures. This was due to the good air flow because of the coarse bulk structure.

The moisture content of chopped wood depends on the relative humidity and the temperature in the boxes. It does not fall below 45% for coarse and fine chips and reaches approximately 30% for chunks after storage for 6 months.

The pH runs from 6 to 8 and chunks have the lowest values. There is a close connection between values of pH and growth of fungi.

During storage, mesophilic and termophilic fungi develop of the genera *Alternaria, Aspergillus, Cladosporium, Mucor* and *Penicillium*.

The growing of fungi corresponds to the temperature in the box and the outside air temperature, but it does not depend on the moisture content of the wood as long as it is between 30 and 60%. The number of mesophilic fungi does not show a relationship to the length of the wood chips, but there is a close connection between the number of particles of thermophilic fungi and the length of the chips (*Figure 9*).

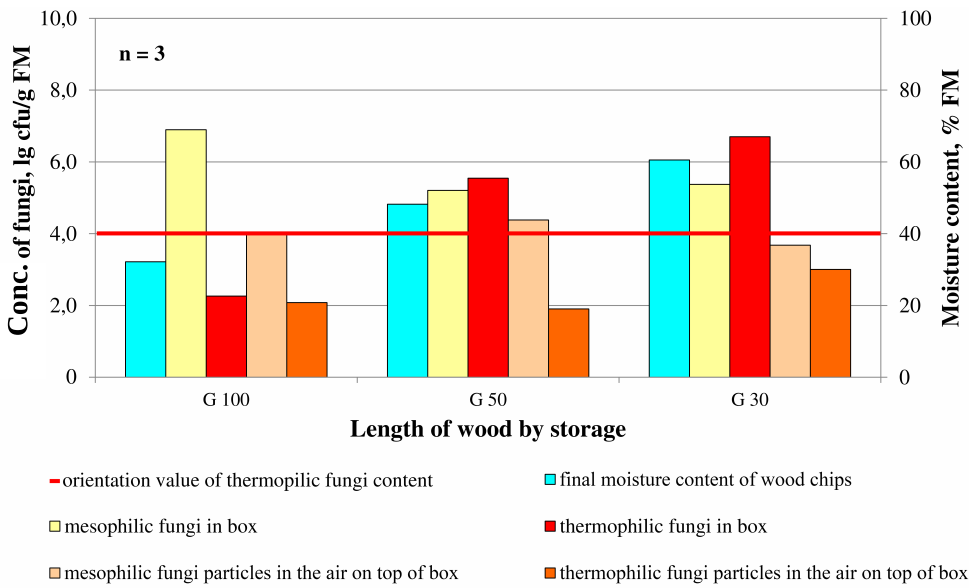

Figure 1. Average of fungi in the box and the concentration of fungal particles in the air of chunks (G 100), coarse (G 50) and fine chips (G 30) after storage for six month

During the examination a special focus was put on the development of thermophilic fungi, because they may be allergen, toxic and fungus pathogenic. The most important thermophilic fungus *Aspergillus fumigatus*, because it is one of the most pathogenic, can cause allergy reactions and cancer. The highest values were found in fine chips (8.4 lg cfu/g *FM*), which is one order of magnitude higher than in coarse chips, and five orders of magnitude higher than in chunks.

The development of the concentration of fungal particles in the air has a very close connection to the concentration of fungal particles in the boxes, and to the temperature in box. The number of mesophilic fungal particles in the air is related to the relative humidity of the air in the box, but this is not the case with thermophilic fungal particles in the air. The highest value of *Aspergillus ssp.* in the air was measured for fine chips (4.6 lg cfu/g *FM*), which is one order of magnitude higher than for coarse chips, and two orders of magnitude higher than for chunks. At present, there is no regulation for the limit of fungi content in the air of wood chips storages neither in Germany nor in Hungary. Therefore, the orientation value limit according to TRBA 430 (compost processing) of 4.0 lg cfu/g should be used.

Storage of coarse chips of poplar from short rotation has several advantages compared to fine chips. During the 6 months of storage the temperature in coarse chips was similar to fine chips, but the moisture content after the second month of storage is less than in fine chips, and after 6 months it reaches approximately 30%. The amount of mesophilic fungal particles in a box of coarse chips is similar to fine chips, but the number of thermophilic fungal particles is one order of magnitude less than in fine chips. This tendency was also found in fungi content in the air above the top of boxes. Storage of chunks has the most advantages, but this length of wood is not easy to handle. Compared to general form of storage fine chips, coarse chips have a better quality and are still convenient to handle. Further improvements are needed to reduce the concentration of fungal particles in the box of coarse chips as well as fungi content in the air and to speed up the drying of stored wood. Aeration with ambient or heated air could be solutions but this would increase production costs.

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