# 11

# *Miscanthus as Raw Materials for Bio-based Products*

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**Abstract**

There is great interest in products from Miscanthus because large quantities of biomass can be produced annually. There are simple uses such as bedding for animals, mulch for horticulture applications, and insulation to improve energy conservation. Miscanthus has excellent natural absorbent qualities which makes it very attractive for spill management and as a bedding material. Compostable foodservice ware has been produced from Miscanthus to replace products from plastic that do not biodegrade. Building applications include fiberboard, particleboard, and composites. Miscanthus has high-quality cellulose for material applications and is an excellent source of cellulose where high quality is important. Nanocellulose applications from this crop are of interest and this is an active area of research, and cellulose from Miscanthus for paper production is one of the applications that is included in this chapter.

**CONTENTS**

## 11.1 Introduction

Miscanthus harvests provide large quantities of biomass. This chapter includes a review of alternative uses for Miscanthus that is produced at phytoremediation sites and regular agricultural lands. Since the locations and sizes of contaminated sites have diversity, it is good to have many potential uses for the biomass that is produced and harvested (Nsanganwimana et al., 2014). The interest in products that are biodegradable is growing because of pollution associated with plastic products that do not biodegrade.

The major constituents in Miscanthus are cellulose, hemicellulose, and lignin. These substances are very common in grasses, bushes, and trees. Wheat straw, corn stover, switchgrass, giant reed, reed canary grass, bamboo, and many other plants are good sources of cellulose, hemicellulose, and lignin. Because of all of the different sources, there is competition in the marketplace. There are also huge markets for biomass all over the world. The pulp and paper industry is an example. Biomass is used for energy, and it is better to burn renewable carbon than coal. The average breakdown of these components is shown in Table 11.1.

In the development of products from Miscanthus, the importance of making products from renewable biomass rather than from petrochemicals has received significant attention recently (Alexopoulou, 2018; Eschenhagen et al., 2019; Moll et al., 2020; Peças et al., 2018; Wang et al., 2018). Miscanthus removes carbon from the atmosphere as it grows; this carbon can be incorporated into building materials and other bio-based products, thus reducing the time associated with the carbon cycle. Carbon associated with sequestration is rapidly removed from the atmosphere and stored in bio-based products for many years.

Some products from Miscanthus are easy to implement and have use at many locations in numerous formulations. Examples of applications that require little processing of the Miscanthus include bedding for livestock and mulch in horticulture applications. It can also be employed as a soil

**TABLE 11.1**

Miscanthus Biomass Dry Weight Composition (wt. %)

| Parameter | Value |
|---|---|
| Cellulose | 42–50 |
| Hemicellulose | 25–28 |
| Lignin | 12–16 |
| Ash | 2.5–3 |
| Water | 10.5 |

amendment to add organic carbon and nutrients to a site. Like other types of biomass, Miscanthus pellets can be used as a fuel in stoves designed to burn pelletized wood and another biomass. This chapter will review the utilization of Miscanthus in bio-based materials.

## 11.2 Material Products

### 11.2.1 Agricultural Products

#### *11.2.1.1 Bedding Applications*

Bedding is an important resource for raising confined livestock. Due to its similarity to other agriculture materials employed in this application, over the last 10 years, there has been growing interest in Miscanthus as a high-quality product as bedding for poultry, pigs, sheep, cattle, and horses. One of the advantages of this application is that it has value in many locations. Its use in this application is straightforward, and it can be used directly without processing. It has good absorbent qualities, and it lasts longer than many other alternatives (Van Weyenberg et al., 2015). It is a clean product; the addition of the used bedding (Miscanthus with manure added) to soil has been shown to improve soil quality.

#### *11.2.1.2 Mulch Applications*

Mulch is used in many locations having diverse beneficial uses. Miscanthus may be used as a sustainable mulch in gardens and other horticulture applications such as in a new orchard (Samson et al., 2018). Mulch formed from the crop improves the aggregate stability of the soil to which it is applied. The increase in organic matter formation results in increases in the microbial numbers and earthworm populations. Phosphorus and potassium concentrations often increase while evaporation, weed growth, and soil erosion are reduced. This application is simple and it provides a good alternative for harvested Miscanthus in many countries.

### 11.2.2 Insulation

Miscanthus may be used for insulation in buildings to improve energy efficiency. A very clear example of this application was demonstrated in Wales with the construction of a house utilizing baled Miscanthus during 2017

(Construction Manager Magazine, 2017). Once framed, Miscanthus bales are placed within the frame in a manner similar to that employing wheat straw bales. The demonstration project was a collaboration between the University of Aberystwyth, the Centre for Alternative Technology, UK, and Terravesta (a company specializing in Miscanthus technology). In addition to taking advantage of Miscanthus as insulation, a primary goal is to reduce the large carbon footprint associated with conventional housing construction.

As an insulation material, harvested product may be used directly. However, there are several processing alternatives in using Miscanthus for insulation (Moll et al., 2020). A comprehensive review of insulation materials from biomass is available (Liu et al., 2017). Low thermal conductivity is important in insulation materials. In some applications sound absorption is very important as well. There is a growing interest in renewable materials because of the importance of reducing greenhouse gas emissions. This has resulted in an increase in the use of natural biomass insulation materials (Bozsaky, 2019) with a patent being issued for such applications (Huesemann-Lammert, 2006).

In 2012 Karl Schock, a German engineer, began the development of an insulating board based on Miscanthus or Napier grass. These are now fabricated through a German company, ISOCALM (GmbH, 2012), and are marketed as plaster carrier mats with thermal insulation. The reported thermal conductivity is 0.45 W $m^{-1}$ $K^{-1}$.

Cardenas et al. (2015) demonstrated the use of Miscanthus as a block-type insulation material. While exploring formulations and processing conditions, thermal conductivities ranging between 0.079 and 0.116 W $m^{-1}$ $K^{-1}$ were obtained. The flexural strength of the Miscanthus product resembled that of expanded polystyrene, type IX.

Biomass insulation materials can be used in the natural form as some of the examples above illustrate. However, two obvious issues of concern with thermal insulation applications are fire safety and the impact of biological organisms using the Miscanthus as a food source. Any application as an insulation material must meet product standards related to fire safety. The integrity of the material must remain even if microbes and other organisms are present. Additives such as borax and aluminum sulfate may be added to improve fire resistance and reduce mold growth (Lopez Hurtado et al., 2016). Formulations have been reported which include ~1.75 wt.% borax, 1.75 wt.% sodium carbonate, and 0.5 wt.% fungicide.

The experience gained from formulating cellulose insulation with recycled paper may well be applicable. The thermal conductivity of cellulose insulation is approximately 0.040 W $m^{-1}$ $K^{-1}$; that value increases with moisture content. Low moisture content is desirable as it does not support mold growth. Borate salts, boric acid, and aluminum sulfate are often mixed into cellulose fibers to prevent combustion and mold growth (Lopez Hurtado et al., 2016).

### 11.2.3 Composites, Building Materials, Cement

The construction industry relies on a diverse array of board products in which lignocellulose fibers and particles take a variety of forms. These products include plywood, particleboard, fiberboard, and strand board. All of these products typically involve the use of some kind of bonding agent. Typical fiberboard compositions are similar to 82% of wood/lignocellulose, 9% of resin, 1% of paraffin, and 8% of water.

Fiberboard and particleboard can be produced from Miscanthus and used as insulation and paneling (Tajuddin et al., 2016). Particleboard from this crop has good qualities when produced by hot pressing and steam processes. The data in Table 11.2 below provide data on a Miscanthus fiberboard fabricated by Velasquez et al. (2002). Property data for medium-density fiberboard is provided as a comparison.

Lignin has been used as an adhesive in the production of particleboard. It has a glass transition temperature of about 200°C and is an effective binder when particleboard is produced by hot pressing. Good results have been obtained using Miscanthus. This was the approach employed by Velasquez et al. (2002) and Salvadó et al. (2003). An example of hot-pressing conditions is 180°C and 5.3 MPa for 10 minutes, yielding a board thickness of 5 mm and product density of 1.0 g $cm^{-3}$ (Tajuddin et al., 2016). In a comparison with other natural fibers, Miscanthus had the largest value of modulus of rupture at 61 MPa. In some work, additional lignin is added to improve bonding (Hubbe et al., 2018). While there has been significant progress in the development of insulation and building materials from Miscanthus biomass, particle size, the aspect ratios of the cellulose fibers, and bonding of particles are areas of ongoing research (Moll et al., 2020).

The development of lightweight concrete through the incorporation of biomass is not a new concept with a patent issued in 2008 with the assignee being Miscanthus-Holdings, SA (Luxembourg) (Hohn, 2008). Several studies of Miscanthus-based lightweight concrete have been reported (Chen et al., 2017, 2020; Ezechiels, 2017; Waldmann et al., 2016). In addition

**TABLE 11.2**

A Comparison of Properties for a Miscanthus Fiberboard versus Typical Data for Medium-Density Fiberboard

| | Density ($Mg\ m^{-3}$) | Specific Modulus ($MPa\ kg^{-1} m^3$) | Rupture Modulus (MPa) | Thickness Swelling | Water Adsorption | Reference |
|---|---|---|---|---|---|---|
| Miscanthus fiberboard | 0.99–1.2 | 6.0 | 50–60 | 5%–60% | 20%–40% | Velasquez et al. (2002) |
| Regular medium-density fiberboard | 0.9–1.0 | ~6–8 | 60–90 | - | - | CES Edupack (2017) |

to producing a lower density concrete, formulations have been developed that have attractive acoustic absorption properties (Chen et al., 2017) and improved environmental impact (Courard & Parmentier, 2017). Typical densities are in the range of 0.65–1.25 Mg $m^{-3}$. A thermal conductivity of 0.17 W $m^{-1}$ $K^{-1}$ was reported at a density of 0.800 Mg $m^{-3}$. The goal has been to achieve compressive strengths exceeding 2.5 MPa; a 9 vol% fiber content has been shown to reduce the density by 20%. The volume content of the fiber in the mix is the important metric. It is important to realize that a fiber content of 9 vol% corresponds to 0.98 wt.% in the mix.

### 11.2.4 Composite Materials

The incorporation of Miscanthus fibers in composites has been investigated and the results have generated significant interest in developing products for use in buildings, vehicles, and other applications (Moll et al., 2020; Muthuraj et al., 2017). The amount of each component in the system, the dispersion of the fibers within the matrix, the particle size and aspect ratio of the Miscanthus fibers, the conditions of processing are important variables in producing composites for specific applications (Moll et al., 2020; Nagarajan et al., 2013). Materials in composites should be selected based on the desired properties for the application. The material properties of green composites have been reviewed and compared to those of other materials (Dicker et al., 2014). Biocomposites have the potential of lower costs and lower densities when compared to more traditional polymer matrix composites.

Miscanthus fibers have been incorporated into biocomposites. While any number of resin systems could be employed as the matrix, the materials selected for the matrix should be biodegradable if the biocomposite is to be truly biodegradable (Muthuraj et al., 2017). Polylactic acid, maleic anhydride, and poly(butylene succinate) (Muthuraj et al., 2015), poly(3-hydroxybutyrate-co-hydroxyvalerate) (Zhang et al., 2014), and biodegradable binary blends (Muthuraj et al., 2017) are examples of matrices used with Miscanthus fibers to form biocomposites.

Miscanthus fiber length has been found to be an important variable for impact strength (Muthuraj et al., 2016). Nanocellulose fibers have excellent properties when they are incorporated into composites (Barbash et al., 2019, 2020; Yang et al., 2019). The crop can be used as a raw material for the production of nanocellulose and cellulose nanocrystals (Cudjoe et al., 2017). Cellulose nanofibers may have crystalline domains, width between 3 and 20 nm, and length between 100 and 4000 nm (Yang et al., 2019). Nanocrystalline films have been formed with tensile strengths ranging from about 50 to 100 MPa (Barbash et al., 2020). The cellulose in Miscanthus has excellent quality for material applications, and it can be produced in large quantities at a reasonable price.

### 11.2.5 Hemicelluloses

Hydrothermal processes may be used to extract hemicelluloses from Miscanthus at temperatures from 160°C to 180°C (Wang et al., 2018; Xiao et al., 2017). Arabinoxylans are the most common hemicellulose polymers in Miscanthus (Schäfer et al., 2019). Hydrolysis of the hemicellulose yields mostly xylose and a small amount of arabinose (Schäfer et al., 2019). For some applications of cellulose, it is beneficial to remove most of the hemicellulose. There is a market for xylose as a raw material for fermentation and other uses.

## 11.3 Processing of Miscanthus to Fibers, Pulp, and Papers

Pulp for paper production is divided into three main categories (Liu et al., 2018): wood fiber, nonwood fiber, and waste paper; the shares of which in the pulp and paper industry are currently 63%, 3%, and 34%, respectively. Nevertheless, the increasing potential of nonwood resources is a consequence of decreasing of forest resources (Lwako et al., 2013). The overall potential of nonwood plant raw materials which can be processed to pulp is about 2.5 billion tons per year and is renewed annually (Saijonkari-Pahkala, 2001). The use of nonwood plant raw materials in the production of pulp goes back to the origins of the paper industry and remains an urgent focus for the industry as forestry resources diminish (Ververis et al., 2004). Promising alternative plants include different crops, and Miscanthus is a leading candidate (Danielewicz et al., 2018) due to its high growth rates, high lignin content, and ability to grow on marginal and degraded lands, where the food production is prohibited. This latter factor eliminates competition with food production. The pulp from perennial grass biomass can to be added to the existing wood feedstock (Bocianowski et al., 2019a, b), be processed separately (Danielewicz et al., 2015), or mixed with waste papers (Cappelletto et al., 2000).

Generally, the paper manufacturing process has several stages, i.e., raw material preparation and handling, pulp manufacturing, pulp washing and screening, chemical recovery, bleaching, stock preparation, and papermaking (Bajpai, 2018). Paper production is basically a two-step process in which a fibrous raw material is first converted into pulp, and then the pulp is converted into paper. The harvested wood is first processed so that the fibers are separated from the unusable fraction of the wood, the lignin. Pulp making can be done mechanically or chemically. The pulp is then bleached and further processed, depending on the type and grade of paper that is to be produced. In the paper factory, the pulp is dried and pressed to produce paper sheets. Post use, an increasing fraction of paper and paper products is recycled, which avoids landfilling or incinerating.

For papermaking, the internodes of Miscanthus stalks have better cellular composition than the nodes and pith. The stalks require less alkali for Kraft pulping compared to birch (Danielewicz et al., 2018; Kordsachia & Patt, 1991).

The technique used for the pulping operations consists of three procedures: preliminary dry-mechanical treatment which initially compresses the crop's stems, a high yield pulping process, followed by a peroxide bleach sequence. Cappelletto et al. (2000) argued that cells found in biomass, i.e., epithelial, sclerenchyma, parenchyma, and medullar rays do not possess the correct dimensions for papermaking. Hence, it is necessary to reduce the number of these cells prior to the pulping process by dry-mechanical treatment. This divides the raw material into uniform segments and to remove leaves and pith. In turn, this pretreatment decreases the chemical consumption during pulping, thus reducing pollution of wastewater. To generate papermaking pulps from fibrous fractions of Miscanthus, a four-stage mechanical pretreatment operation was designed (Cappelletto & Mongardini, 1997). The first stage compacted the Miscanthus stalks by cutting the raw material using a blade mill. The second step used fans to transport the cut material, and the third stage contained a cyclone that was utilized to divide light fractions. Finally, the last stage separated hefty fines. These operations help to obtain a higher number of fibers because foreign matter like dust, sand, and pebbles are removed; it eliminates useless material such as leaves, pith, epithelial, and parenchyma cells of stems. The resulting material will contain a higher percentage of fibers.

There are few standard methods for obtaining pulp from wood and non-wood raw materials, i.e., the sulfate, sulfite, and neutral-sulfite methods. These negatively influence the environment because of the application of sulfur-containing reagents for lignin removal from plant materials. Most of the lignin is removed during cooking, but there is some residual lignin that can be removed in an additional stage by bleaching, using chlorine-based and oxygen-based chemicals (Smook, 2002).

It has been shown that variations of the growing conditions may considerably influence the cooking results during pulping of *Miscanthus sinensis* (Kordsachia et al., 1993). Two different raw material samples were obtained from 3-year-old plantations in Germany and Sweden, and harvested in spring. The raw material grown in Germany gave better cooking results, in particular, higher pulping yields (Table 11.3).

**TABLE 11.3**

Comparison of Pulp Strength of Two Different Sources of *M. sinensis*

| Country of Origin | Cooking Process | Breaking Length (km) | Tear Strength (cN) | Runability Factor |
|---|---|---|---|---|
| Germany | AS/AQ | 8.32 | 70.8 | 7.6 |
| | NS/AQ | 8.12 | 61.8 | 7.1 |
| Sweden | AS/AQ | 7.80 | 74.0 | 7.6 |
| | NS/AQ | 7.71 | 80.8 | 7.9 |

*Source:* Modified from Kordsachia et al. (1993).

Cooking of the leaf-fraction results in much lower yield, brightness, and pulp viscosity in comparison with stalks (Kordsachia et al., 1993). However, when whole plant material is cooked, the adverse effect of leaves is hardly evident. Miscanthus sinensis has some outstanding features in comparison with other nonwood pulping raw materials, i.e., high delignification rate obtained with a low chemical change. The high yield, good bleaching ability, and excellent strength properties nearly match those of pulps prepared from poplar.

Organosolvent delignification has been suggested as an environmentally friendly process and an alternative way for obtaining pulp. Organic reagents have the potential to remove lignin and hemicelluloses at boiling temperatures. A variety of organic solvents such as esters, alcohols, ketones, and organic acids have been offered for cooking (Barbash et al., 2011). Among organic solvents, acetic acid is regarded as a potential agent to achieve extensive delignification due to its relatively low cost. The application of hydrogen peroxide during cooking promotes delignification of raw materials; increased brightness can also be achieved by delignification with peroxyl compounds. At the same time, less pronounced degradation of the cellulose is observed during cooking with such compounds. The cooking process is carried out at low temperature which helps to reduce energy consumption.

## 11.4 Production of Pulp from *M.* × *giganteus* Biomass Produced on Pb-Contaminated Soil

A laboratory experiment was done to evaluate the production of pulp from Miscanthus biomass growth in Pb contaminated soil with concentrations in between 583 and 604 mg kg$^{-1}$; other trace elements, Mn, Ni, Cu, Zn, Sr, Zr, were detected in smaller concentrations (Table 11.4). The biomass for production of pulp was harvested in spring 2018.

**TABLE 11.4**

Content of Trace Elements in the Soil of Three Replicated Plots, mg kg$^{-1}$

| Trace Elements | Plot 1 | Plot 2 | Plot 3 |
|---|---|---|---|
| Mn | 452 ± 34.31 | 764.93 ± 50.32 | 468.19 ± 34.98 |
| Fe | 15,975 ± 92 | 16,949 ± 95 | 17,799 ± 97 |
| Ni | 16.29 ± 8.40 | 14.48 ± 8.65 | 17.34 ± 8.73 |
| Cu | 127.70 ± 5.83 | 134.80 ± 6.21 | 130.25 ± 6.20 |
| Zn | 130.15 ± 6.33 | 174.99 ± 7.18 | 146.42 ± 11.64 |
| Sr | 78.72 ± 2.08 | 80.72 ± 2.11 | 76.51 ± 2.16 |
| Zr | 665.84 ± 4.01 | 678.75 ± 4.08 | 660.72 ± 4.10 |
| Pb | 604.16 ± 9.60 | 612.01 ± 8.67 | 583.15 ± 8.83 |

Cooking of pulp from Miscanthus stalks was done by the peracetic method, which is environmentally friendly than traditional sulfate and sulfite methods of cellulose production and is characterized by lower energy costs compared with conventional and other organosolvent methods of delignification (Barbash et al., 2011, 2020).

The chemical composition of different parts of the Miscanthus stalks in comparison with other nonwood plants raw materials and hardwood and softwood species is given in Table 11.5.

It can be seen that according to the content of cellulose the mixture of Miscanthus stalks exceeds the content of cellulose in a mixture of wheat straw, rapeseed, hemp, wood; however, it is similar to a mixture of flax. Miscanthus stalks have a relatively high lignin content, close to the lignin content in rapeseed and spruce stems; have a close mineral content (ash

**TABLE 11.5**

Chemical Composition of Different Parts of Nonwood Plant Raw Materials and Wood, % from Mass of Absolutely Dry Raw Materials

| | | | Solubility in | | | |
|---|---|---|---|---|---|---|
| **Parts Plants** | **Cellulose** | **Lignin** | **Water** | **NaOH** | **RFW[a]** | **Ash** |
| *M. × giganteus* | | | | | | |
| Mixture | 53.3 ± 1.47 | 25.5 ± 0.645 | 3.3 ± 0.49 | 25.1 ± 0.79 | 1.86 ± 0.15 | 1.71 ± 0.14 |
| Internodes | 55.8 ± 1.48 | 25.1 ± 0.63 | 3.0 ± 0.48 | 24.1 ± 0.78 | 2.04 ± 0.16 | 1.60 ± 0.13 |
| Knots | 46.6 ± 1.39 | 27.0 ± 0.65 | 4.2 ± 0.51 | 27.9 ± 0.81 | 1.81 ± 0.17 | 1.77 ± 0.15 |
| *Wheat Straw* | | | | | | |
| Mixture | 44.3 ± 1.33 | 16.5 ± 0.58 | 10.1 ± 0.5 | 38.4 ± 0.99 | 5.2 ± 0.2 | 6.6 ± 0.18 |
| Stalk | 46.2 ± 1.34 | 18.6 ± 0.60 | 6.0 ± 0.48 | 36.2 ± 0.98 | 4.6 ± 0.19 | 4.2 ± 0.17 |
| Leaves | 42.3 ± 1.35 | 15.2 ± 0.59 | 9.8 ± 0.52 | 40.1 ± 1.05 | 6.5 ± 0.19 | 9.4 ± 0.19 |
| *Rape* | | | | | | |
| Stalk | 35.6 ± 1.28 | 22.9 ± 0.65 | 11.6 ± 0.52 | 25.6 ± 0.81 | 4.8 ± 0.19 | 3.3 ± 0.16 |
| Root | 28.3 ± 1.29 | 27.7 ± 0.71 | 10.9 ± 0.53 | 31.5 ± 0.82 | 2.4 ± 0.21 | 5.4 ± 0.18 |
| *Flax* | | | | | | |
| Mixture | 59.6 ± 1.41 | 10.9 ± 0.58 | 4.1 ± 0.49 | 13.6 ± 0.77 | 4.7 ± 0.19 | 2.4 ± 0.14 |
| Fiber | 69.5 ± 1.52 | 6.1 ± 0.61 | 3.7 ± 0.43 | 13.4 ± 0.66 | 3.6 ± 0.11 | 1.5 ± 0.12 |
| Wood part | 42.0 ± 1.36 | 23.6 ± 0.73 | 5.2 ± 0.54 | 19.4 ± 0.82 | 5.2 ± 0.24 | 2.8 ± 0.15 |
| *Hemp* | | | | | | |
| Mixture | 46.2 ± 1.33 | 17.0 ± 0.53 | 6.9 ± 0.49 | 25.0 ± 0.69 | 2.2 ± 0.13 | 2.6 ± 0.12 |
| Bast | 67.8 ± 1.51 | 6.5 ± 0.48 | 3.8 ± 0.47 | 20.8 ± 0.57 | 1.9 ± 0.12 | 1.5 ± 0.11 |
| Wood part | 42.2 ± 1.34 | 12.5 ± 0.69 | 5.1 ± 0.53 | 22.9 ± 0.72 | 3.7 ± 0.15 | 2.9 ± 0.14 |
| *Wood* | | | | | | |
| Birch tree | 41.0 ± 1.29 | 21.0 ± 0.54 | 2.2 ± 0.52 | 11.2 ± 0.68 | 1.8 ± 0.15 | 0.5 ± 0.07 |
| Spruce | 46.1 ± 1.35 | 28.5 ± 0.61 | 7.3 ± 0.54 | 18.3 ± 0.59 | 2.9 ± 0.18 | 0.2 ± 0.05 |

*Source:* Modified from Barbash et al. (2018).
[a] RFW, resins, fats, waxes.

**TABLE 11.6**

Content of the Trace Elements in Pulp, mg $kg^{-1}$

| Trace Elements | Sample 1 | Sample 2 | Sample 3 | Average Value |
|---|---|---|---|---|
| Ti | 3.64 ± 1.12 | 2.97 ± 1.08 | 3.53 ± 1.40 | 3.38 ± 1.20 |
| Mn | 2.24 ± 0.25 | 2.21 ± 0.23 | 2.96 ± 0.31 | 2.47 ± 0.26 |
| Fe | 16.02 ± 0.35 | 16.13 ± 0.33 | 25.02 ± 0.47 | 19.06 ± 0.38 |
| Ni | 0.24 ± 0.08 | 0.28 ± 0.08 | 0.29 ± 0.10 | 0.27 ± 0.09 |
| Cu | 88.77 ± 0.43 | 81.31 ± 0.39 | 104.67 ± 0.50 | 91.58 ± 0.44 |
| Zn | 23.14 ± 0.21 | 20.94 ± 0.19 | 28.55 ± 0.26 | 24.21 ± 0.22 |
| Sr | 0.22 ± 0.01 | 0.19 ± 0.01 | 0.24 ± 0.02 | 0.22 ± 0.01 |
| Sn | 0.71 ± 0.06 | 0.62 ± 0.06 | 0.76 ± 0.07 | 0.70 ± 0.06 |
| Pb | 13.06 ± 0.12 | 11.68 ± 0.12 | 15.08 ± 0.16 | 13.28 ± 0.13 |

content) to other nonwood plant materials; and significantly exceed the value of this indicator in softwood and hardwood (Danielewicz et al., 2015). The organosolvent peracetic pulp from *M. ×giganteus* with the duration of cooking 90 minutes was selected for investigation of physical properties. The strength properties of handmade sheets from peracetic pulps had the following physical and mechanical parameters: breaking length 8300 m, tear resistance 310 mN, burst resistance 220 kPa. The obtained data testify to high physical and mechanical indicators and the possibility of using this cellulose in the production of various types of paper and cardboard (Barbash et al., 2020).

This pulp was analyzed for the content of Pb and other elements; using the X-Ray Roentgen-fluorescence analysis, results are presented at Table 11.6. The concentrations of Mn, Fe, Ni, Cu, Zn Sr, Pb and Zr are limited, so pulp may be used for further processing.

The research describes the conversion process of *M. ×giganteus* biomass produced in trace elements contaminated soil to pulp using peracetic treatments. The delignification of initial raw material yielded pulp with a low lignin and ash content and high brightness at low energy costs and in a short cooking time with limited concentration of trace elements.

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