Comparison of the Properties of Cellulose Obtained from Various Sources

E A Petukhova and E N Teleshova
Yaroslav-the-Wise Novgorod State University, 41 B. St. Petersburgskaya ul., Veliky Novgorod, Russian Federation
E-mail: Elena.Petuhova@novsu.ru

Abstract. The article discusses the structure, structure and properties of cellulose obtained from various natural sources of plant origin. The physical and mechanical properties of celluloses (content of α – cellulose, determination of the mass fraction of pentosans; determination of the copper number; viscosity characteristics; determination of the degree of purity, moisture content and ash content and determination of the average molecular weight, degree of polymerization and content of aldehyde and carboxyl groups), interaction with nitrogen acid as well as the ability of various cellulose samples to complex formation with copper ions.

1. Introduction
The unique and chemically interesting structure of cellulose determines its wide application in various fields. The most important areas and sectors of the use of cellulose are pulp and paper, food industry, medicine, biotechnology, ecology, cosmetics industry, agriculture [1, 5–8]. Cellulose is the main component of plant organisms [2–4, 9,10]. There are 2 types of cellulose: natural cellulose and regenerated cellulose. The natural type of cellulose includes, for example, cellulose obtained from plants of such families as Gossypiumae, Linaceae, Cannabaceae. Cellulose is a linear homopolysaccharide. Its macromolecules are formed by β-D-glucopyranose units, which are interconnected by β-(1 → 4)-glycosidic bonds.

The general structure of this polymer is depicted by the formula shown in figure 1.

![Figure 1. Structural formula of cellulose macromolecule [1–5].](image)

2. Objects and methods of research
The material for the research was vegetable raw materials of various origins, containing cellulose. The following materials were used as objects of research in the work:

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd
1. Cellulose fiber from outgrowths of epidermal cells of seeds (hairs) of cultivated cotton species (Gossypium herbaceum L.).

2. Linseed pulp. It is a product of processing flax fibers of Linum usitatissimum plants: fiber flax, mid-grain flax, crown flax and creeping flax. We have chosen fiber flax as the most affordable in the territory of the Novgorod region.

3. Pulp obtained from wood chips of Pícea Abies spruce. Cellulose obtained from samples of annual plants of the genus Triticum. Wheat straw was used for the work.

Isolation of cellulose was carried out according to generally accepted methods. The determination of the investigated physical and mechanical properties, as well as the analysis of the products of chemical reactions were carried out by spectrophotometric, potentiometric methods.

3. Results and discussion

In accordance with the work plan and the tasks set, at the first stage, the important physical and mechanical characteristics of cellulose samples were determined, such as: the content of α - cellulose, the determination of the mass fraction of pentosans; determination of the copper number; viscosity characteristics; determination of the degree of purity, moisture content and ash content and determination of the average molecular weight, degree of polymerization and the content of aldehyde and carboxyl groups. The data obtained are shown in table 1.

| Parameter                              | Cotton plant | Fiber flax | European spruce | Common wheat |
|----------------------------------------|--------------|------------|-----------------|--------------|
| Content of α–cellulose, %              | 97.3         | 73.0       | 72.7            | 72.0         |
| Moisture content, %                    | 4.0          | 4.0        | 5.8             | 3.7          |
| Ash content, %                         | 0.32         | 0.35       | 0.51            | 0.34         |
| Viscosity, cPa * s                     | 31.639       | 27.052     | 17.639          | 22.053       |
| Molecular weight                       | 69·10³       | 44·10³     | 80·10³          | 40·10³       |
| Purity, %                              | 90.0         | 88.0       | 70.7            | 82.0         |
| Copper number, g/100g                  | 0.321        | 0.535      | 0.461           | 0.522        |
| Mass fraction of groups-COOC          | 9.4          | 9.7        | 27.4            | 9.7          |
| Mass fraction of groups - COOH         | 17.8         | 14.0       | 14.0            | 14.6         |
| Mass fraction of pentosans, %          | 4.5          | 4.4        | 7.0             | 4.8          |
| Output in terms of feedstock, %        | 50.4         | 47.6       | 20.0            | 50.8         |

As can be seen from the results obtained, the physicochemical properties of celluloses isolated from various plant raw materials, and which subsequently determine the direction of processing of specific cellulose samples, differ very slightly in almost all indicators. The exception is wood pulp. The reason for this may be the initial composition of plant materials (increased resin content), processing modes.

At the second stage, a study of the chemical activity of cellulose samples was carried out. The study of the chemical activity was carried out by analyzing the products obtained by the dinitrification reaction.

The analysis of the obtained samples of nitro compounds showed that under the same conditions the sample obtained from cotton is nitrated better than other samples, as evidenced by the nitrogen content, and the worst of all is the sample obtained from European spruce. This is due to the presence of contaminants in it, so the process of obtaining the cellulose itself was associated with great difficulties.

The data obtained are shown in table 2.

We also studied the metal-binding ability of cellulose samples of various origins with respect to copper ions from aqueous solutions.
Table 2. Characteristics of cellulose dinitrate samples.

| Parameter                  | Sample               | Cotton plant | Fiber flax | European spruce | Common wheat |
|----------------------------|----------------------|--------------|------------|-----------------|--------------|
| End product yield, %       |                      | 74.5         | 70.6       | 50.0            | 71.4         |
| Nitrogen content, %        |                      | 12.4         | 12.6       | 10.5            | 12.9         |
| Solubility in acetone, %   |                      | 97.5         | 65.2       | 55.0            | 70.4         |

The study of the metal-binding ability of cellulose samples in relation to Cu$^{2+}$ ions was carried out under static conditions with stirring under standard conditions: a temperature of 298 K (25 °C) and pH = 6.5.

The efficiency of the process of binding copper ions by cellulose of various origins was also calculated. The data obtained are presented in Table 3.

Table 3. Dependence of the efficiency of binding copper ions by various types of cellulose on the time of the process (at an initial concentration of the model solution of 0.25 mg/ml).

| Time of the process, min | Binding process efficiency, % |
|-------------------------|--------------------------------|
|                         | Cotton plant | Fiber flax | European spruce | Common wheat |
| 10                      | 18.2         | 16.1       | 10.4             | 10.9         |
| 15                      | 28.1         | 26.2       | 21.2             | 28.2         |
| 20                      | 29.3         | 32.3       | 32.6             | 34.3         |
| 25                      | 39.4         | 40.4       | 35.7             | 43.6         |
| 30                      | 44.5         | 47.6       | 40.8             | 50.6         |
| 60                      | 46.7         | 50.7       | 44.6             | 52.2         |
| 120                     | 48.3         | 51.3       | 44.6             | 52.5         |
| 180                     | 48.3         | 51.3       | 44.6             | 52.5         |
| 240                     | 48.3         | 51.3       | 44.6             | 52.5         |
| 360                     | 48.3         | 51.3       | 44.6             | 52.5         |

Figure 2. Kinetic curve of the binding process of Cu$^{2+}$ by cellulose samples of various origins at $T = 298$ K, $pH = 6$, $m_{sample} = 1.0$ g/100 cm$^3$, where 1,2,3 and 4, respectively, are samples of Cotton plant, Fiber flax, European spruce and Common wheat cellulose.
According to the results of the experiments, all varieties of cellulose showed average metal-binding properties, binding from 44.6 to 52.5% of copper cations.

The data obtained show that the process of binding of copper ions is most intensive only in the first 10-20 minutes. After 2 hours of contact of a cellulose sample with a solution of copper sulfate, no changes in the concentration of copper ions were observed in the direction of decreasing. The kinetics of copper ion binding by cellulose samples is shown in figure 2.

4. Conclusion
As a result of the studies, for which 4 different sources of natural raw materials were selected (cotton plant, fiber flax, European spruce and common wheat), cellulose was isolated with a polysaccharide yield, respectively, 50.4%, 47.6%, 20.0% and 50.8%.

In the study of the physicochemical and chemical properties of the obtained samples, it was revealed that the properties of celluloses isolated from various plant raw materials slightly differ from each other in almost all indicators. An exception is a cellulose sample obtained from the processing of ordinary spruce wood chips. The reason for this may be both the initial composition of plant raw materials and the parameters of the production process.

To study the chemical activity of cellulose samples obtained from various natural sources, we carried out nitration reactions of the samples to dinitro compounds. The data obtained showed that, under the same conditions, the sample obtained from cotton is nitrated better than other samples, as evidenced by the nitrogen content, and the sample obtained from spruce wood is the worst nitrated. This is due to the presence of contaminants in it, so the process of obtaining the cellulose itself was associated with great difficulties.

Experiments were also carried out to determine the metal binding capacity of various cellulose samples. Based on the results of the experiments, it is clearly seen that all cellulose samples are capable of binding copper cations.

References
[1] Atakhanov A A, Mamadierov B, Kuzieva M and Yugai S M 2019 Comparative study of the physicochemical properties and structure of cotton cellulose and its modified forms Chemistry of Plant Raw Materials 3 5–13
[2] Momzyakova K S, Deberdeyev T R, Vershinin M S, Leksin V V, Momzyakov A A and Deberdeyev R Ya 2019 Chemistry of Plant Raw Materials 3 15–21
[3] Astruc J 2017 Isolation of cellulose-II nanospheres from flax stems and their physical and morphological properties Carbohydrate Polymers 178 352–359
[4] Zarubina A N, Ivankin A N, Kuleznev A S and Kochetkov V A 2019 Cellulose and nanocellulose Forestry Bulletin 23 (5) 116–125
[5] Bemiller J N 2019 Cellulose and cellulose-based hydrocolloids Carbohydrate Chemistry for Food Scientists (Third Edition) 1223–240
[6] Rybin B M, Zavrazhnova I A and Rybin D B 2018 Determination of physical parameters of polymers for woodworking by additive functions of group contributions of chemical structural links Forestry Bulletin 22 (2) 68–75
[7] Henschen J, Li D and Ek M 2019 Preparation of cellulose nanomaterials via cellulose oxalates Carbohydrate Polymers 213 (6) 208–216
[8] Amarala H R, Ciprianoa D F, Santosa M S, Schettino M A, Ferretib J V T, Meirelesb C S, Pereirac V S, Cunhaa A G, Emmericha F G and Freitasa J C C 2019 Production of high-purity cellulose, cellulose acetate and cellulose-silica composite from babassu coconut shells Carbohydrate Polymers 210 (4) 127–134
[9] Ivankin A N, Sanaev V G, Gorbacheva G A, Ageev A K, Kiryukhin D P, Kichigina G A and Kushch P P 2018 Modification of the properties of natural cellulose-containing composite materials by fluoropolymers and telomers of tetrafluoroethylene Proceedings of Higher Educational Institutions. Forestry Bulletin 2 (362) 122–132
[10] Grinshpan D D, Razumeev K E, Beloglav A P and Kudryavtseva T N 2016 Manufacture of textiles using self-extinguishing cellulose-chitosan fibers Clothing Industry 1–2 14–16