Study on the microcrystalline cellulose from medicinal plants

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Abstract. This study employs nitric acid and alkaline hydrolysis methods to extract celluloses from the stems of various medicinal plants, including amaranth, milk thistle, tribulus, and consolida. Furthermore, the research takes a step further by synthesizing microcrystalline cellulose (MCC) from the cellulose extracted from these medicinal plants, employing deep hydrolysis utilizing a mixture of sulfuric acid and hydrogen peroxide. The focus of the investigation extends to comprehending the structural and dimensional attributes of cellulose fibers sourced from milk thistle. This endeavor is aimed at gaining insights into the suspension characteristics of these fibers. Physicochemical attributes and structural characteristics of both cellulose and MCC are meticulously examined. The methods of analysis encompass optical microscopy, infrared spectroscopy (IR), and X-ray diffraction (XRD). These techniques are employed to unveil a comprehensive understanding of the properties and structures inherent in both cellulose and MCC, derived from the medicinal plant sources. Through this multifaceted approach, the research brings to light a comprehensive array of insights. These range from the extraction and synthesis processes to the structural attributes of cellulose and MCC. Such in-depth exploration forms the cornerstone of advancing the utilization of cellulose-based materials in diverse applications, with implications for fields ranging from medicine to materials science.

1. Introduction

In the world, every year in the cosmetic, food, medical and pharmaceutical industries, the use of powdered products obtained by physical and chemical processing of cotton and wood pulp is increasing [1]. One of the products obtained by structural modifications of cellulose is microcrystalline cellulose, which is used as a thickener, emulsifier and stabilizer in place of coarse fiber in digestion [2]. The production of high-content α-cellulose from chemically treated cotton and bleached sulphate cellulose, micro- and nanocrystalline cellulose from low-lignin and hemicellulose is of current importance [3].

In-depth research is being carried out in the world on the isolation of biologically active substances from the composition of medicinal plants and the production of food, medicinal, cosmetic and pharmaceutical products on their basis [4, 5]. In this regard, special attention is paid to the production of chemically inert, solution-resistant, highly absorbent, harmless, tasteless, colorless and odorless fillers for medical preparations, the creation and testing of accelerated technologies for the production of materials belonging to the group of insoluble dietary fibers [6-9].

In Uzbekistan, certain scientific and practical results are being achieved in the development of improved technologies for obtaining structurally modified microcrystalline cellulose. The development strategy of New Uzbekistan identified important tasks of "raising the industry to a new level of quality, deep processing of local raw materials, accelerating the production of finished products, mastering new types of products and technologies". In this regard, it is of great importance to optimize technologies with the introduction of low-stage, continuous processes using local reagents, which makes it possible to reduce energy and capital costs in the production of microcrystalline cellulose obtained from waste (meal) from the processing of cotton, wood and partially medicinal plants, which is used in as a filler in the preparation of drugs, as a sorbent in analytical and preparative chromatography, as an additive in confectionery, bread and meat products in the food industry [10-14].

Currently, research is being carried out on the production of microcrystalline and nanocrystalline cellulose from both cotton, wood, and non-wood plant materials [15-17]. Uzbekistan is rich in medicinal plants. 750 species of more than 4.3 thousand plants of the local flora are considered medicinal, of which 70 species are actively used in

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the pharmaceutical industry. Scientists of the Institute of Chemistry of Plant Substances of the Academy of Sciences of the Republic of Uzbekistan have been engaged in the isolation of biologically active substances from plants of the natural flora of Uzbekistan for many years. The stem is not used; the cellulose parts can be isolated from them and microcrystalline cellulose (MCC) can be obtained from it. MCC is one of the most widely used cellulose derivatives [18-21]. It is used in many areas of human life. MCC from the stem of medicinal plants can be used as a filler for the manufacture of tablets in pharmaceuticals and medicine, replacing MCC obtained from cotton or wood pulp [22, 23].

The scientific significance of the results of the study is explained by the fact that the regularities of the synthesis of microcrystalline cellulose from cellulose obtained from the stems of medicinal plants in a combined way are substantiated, the optimal conditions for obtaining chemically inert, stable in solutions, having high sorption properties, harmless, tasteless, colorless and odorless fillers are determined [24-27].

The practical significance of the research results is explained by the fact that the technology for isolating microcrystalline cellulose from the stems of medicinal plants and chemically processed meal has been improved, which is recommended for use as [28, 29]: a filler in the preparation of medicines, a sorbent in analytical and preparative chromatography, an additive to confectionery, bread and meat products in the food industry.

The purpose of this work is to isolate cellulose from the stems of medicinal plants, synthesize MCCs, and study their features of the supramolecular structure

2. Materials and methods

The stems of medicinal plants (amaranth (*amaranthus caudatus*), milk thistle (*Silybum marianum*), tribulus (*tribulus terrestris*), and *consalida regalis*) cellulose isolated from them were used as initial raw materials, as well as MCC was synthesized from isolated cellulose samples. Cellulose was obtained by the soda method, washed to a neutral medium and dried at a temperature of 105°C for 45 min.

Before synthesizing the microcrystalline portion of cellulose, hydrolysis was performed. The composition and conditions of hydrolysis are a mixture (1:1) of 10% sulfuric acid and 10% hydrogen peroxide, bath modulus 1:10, boiling for 60 min, washing and drying the sample at room temperature. Dried pieces of microcrystalline cellulose were crushed on a laboratory disintegrator. Tablets were made from MCC according to standard methods.

The bulk density of the samples was determined by the gravimetric method. The shape and size of MCC particles were studied using an OPTIKA B-150 microscope (Italy). Determination of the average degree of polymerization (DP) of cellulose samples was carried out by the method of establishing dynamic viscosity using a capillary viscometer, capillary diameter 0.56 mm, according to GOST 14363.2-83. Method for determining the average degree of polymerization. Fractionation of microcrystalline cellulose particles was carried out using a sieve according to GOST 8269.0-97, mesh size: 0.16; 0.315; 0.63; 1.25; 2.5; five; 10; 20; 40 mm.

The IR spectra of the studied samples were taken on an IR-Fourier spectrometer – IRAffinity - 1, (Germany) in the mid-infrared region 4000-500 cm-1 with samples pressed into KBr pellets. The crystallinity index of cellulose samples was calculated using the ratio of optical densities D1370/D2900 according to the method [5] and X-ray diffraction analysis of cellulose samples was performed using a DRON-3M diffractometer. Used Cu-Kα - copper radiation, separated by a nickel filter. Wavelength $\lambda = 1.54178$ Å in the range of reflection angles: $2\theta = 3\text{-}40^{o}$, for amaranth cellulose, $2\theta = 3\text{-}37^{o}$, for amaranth MCC, $2\theta = 3\text{-}39^{o}$, for milk thistle cellulose, $2\theta = 3\text{-}52^{o}$, for MCC milk thistle.

3. Results and discussion

During the cooking of stem samples, the destruction of organic substances occurs. Saccharides and lignins pass into the cooking solution during the cooking process. The output of cellulose and microcrystalline cellulose isolated for all samples is, respectively, within 35-36%, and MCC - 86-87% of the feedstock. Some properties and composition of cellulose and MCC samples are given in Table 1.

The SP of the obtained samples of amaranth and milk thistle cellulose ranges from 844-870, and the MCC is 244-256. A high degree of swelling of MCC in water is observed in amaranth and consalidia.

Table 1 shows that the yield of cellulose from the stalks of milk thistle and tribulus is about 35%, and the yield of MCC from it is 86%. Sorption of moisture, respectively, 14.0 and 13.4%. The bulk density of these samples is within the following limits: cellulose 0.11 - 0.25 g/cm^3; MCC 0.39-0.71 g/cm^3.

Morphology of samples. The shapes and sizes of cellulose fiber fragments were studied using an L&W Fiber Tester automatic analyzer [6]. Structural and dimensional characteristics were determined in a suspension of cellulose fibers from milk thistle. Determination of the average fiber size and fractional composition, their length and width on the L&W Fiber Tester automatic analyzer. The results of the determination are shown in Fig.s 1 and 2. It is

known that the length of the fibers has a great influence on the physical properties: the strength and elasticity of the material.

Table 1. Cellulose yield from stem, MCC yield from cellulose, physicochemical properties of amaranth and milk thistle samples

Raw materials	Yield, %	Swelling in water, % [10]	*moisture sorption, %	Ash content, %	SP	Bulk density, g/cm^3
Amaranth						
Stem	cellulose - 35	209	14.2	0.52	844	0.11
Cellulose	mcc - 86.0	162	12.3	0.13	256	0.41
Milk thistle						
Stem	cellulose - 36	217	11.0	0.48	870	0.13
Cellulose	mcc - 87	181	12.2	0.14	244	0.42
Tribulus						
Stem	cellulose- 34	248	13.4	0.47	825	0.25
Cellulose	mcc - 85	185	10.2	0.12	189	0.39
Consolida						
Stem	cellulose - 30	265	14.1	0.30	780	0.23
Cellulose	mcc - 88	210	10.4	0.15	270	0.71
*Relative air humidity 65%						

A **B**

Fig. 1. A - Sample MCC; **B** – micrograph of milk thistle cellulose fibers (wire diameter 0.3 mm).

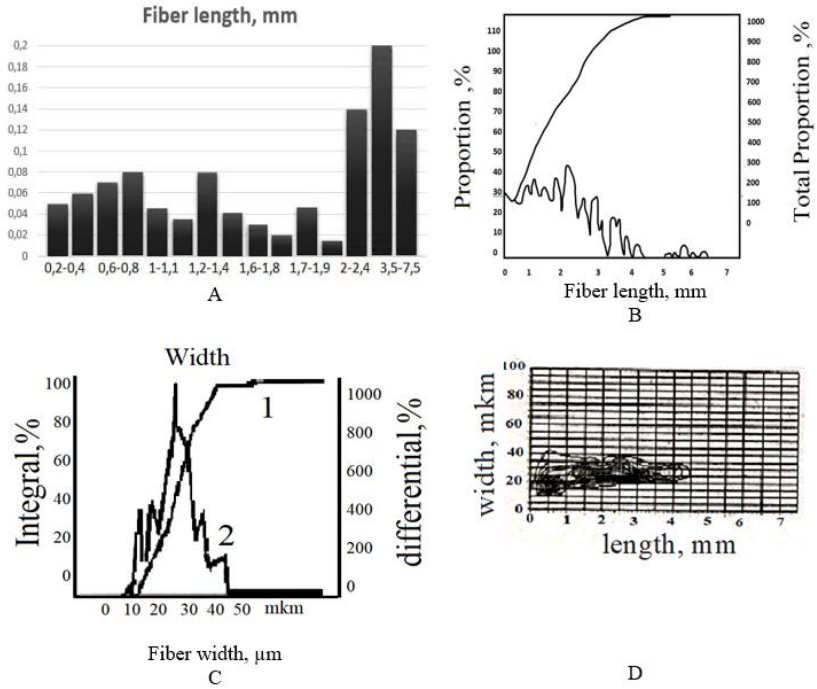

Fig. 2. Fractional composition of milk thistle (*Silybum mariánum*) cellulose samples: A, B – fiber length; C is the width of the fibers; D - the shape of the fibers.

Cellulose from milk thistle was obtained in laboratory conditions. Cellulose fiber was not subjected to mechanical grinding. Therefore, the fiber length is more scattered (from 10 to 50 μm).
Thus, using an automatic analyzer Fiber Tester, we determined the structural and dimensional characteristics in a suspension of milk thistle cellulose fibers, their distribution curves in the form of integral and differential. Fiber analysis results: length from 0.2 to 7.5 mm, width from 10 to 50 microns.
The shapes and sizes of fragments of cellulose fibers and MCC particles were obtained using an OPTIKA-B-150 microscope at a magnification of 100 times. Fig. 3 shows samples of cellulose and MCC of amaranth, milk thistle, and tribulation.

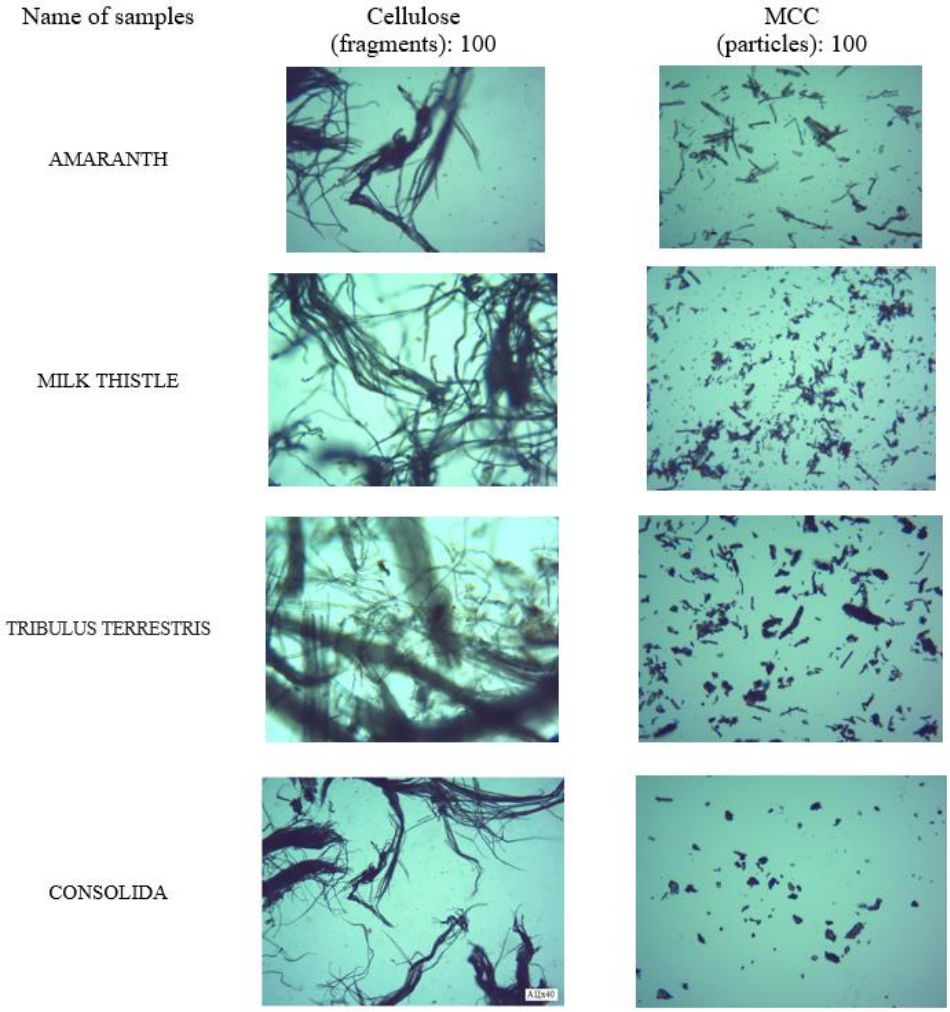

Fig. 3. Micrograph of cellulose fibers and MCC particles.

Cellulose fibers obtained from amaranth and milk thistle have a fibrillar structure. The size of milk thistle particles is somewhat larger than that of amaranth MCC particles, which indicates their structural features.
The particle size of cellulose fibers after hydrolysis decreases several times. The study of samples on a photo device showed the formation of agglomerates, both in cellulose and in MCC. It is characterized with cellulose hydrogen bonds. The photographs show that large agglomerates consist of particles whose size is quite large.
Fig. 4 shows the fractional composition of amaranth MCC: particle size 0.16 mm 60%, particle size 0.315 m 35%, with particle sizes from 0.63 to 2.5 mm make up about 5%.

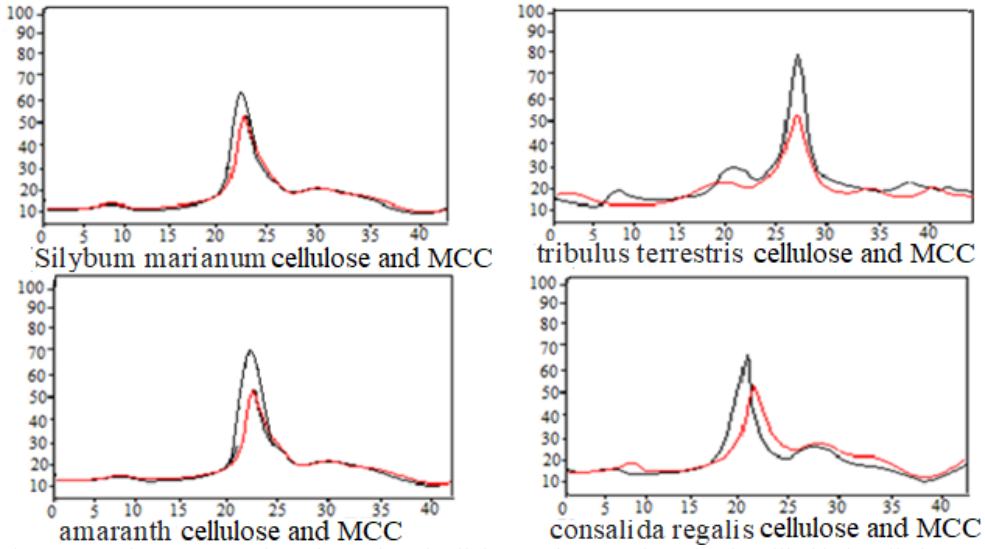

Fig. 4. Intensity curves of X-ray scattering of samples of cellulose and MCC of amaranth, milk thistle, tribulus, and consalidia.

The presence of signals at 2θ = 29, 34° and 2θ = 15-16° indicates the possibility of the existence of several varieties of crystalline elements in cellulose and MCC. The position of the main reflections on the intensity curves of X-ray reflections in the specified range of angles corresponding to the reflection from the planes of the cellulose cell, 110 and 200, respectively, are characteristic of the structural modification of cellulose. The crystallinity index of cellulose samples (I_c) was calculated from the ratio of the height between the intensity of the crystalline peak ($I_{002} - I_a$) and the total intensity (I002) after subtracting the background signal using the Segal method [7]:

$$I_c = I_{002} - I_a / I_{002},$$

where, I_{002} is the maximum diffraction intensity from 200 (I_{002}) at 2θ = 22, I_a is the height of the minimum of the peak at 200 and 110 at 2θ = 19°.

The diffraction patterns are characteristic of the crystalline structural modification of cellulose with Miller indices 002 and 001. Quantitative X-ray diffraction analysis of cellulose and MCC samples makes it possible to determine the degree of crystallinity (crystalline blocks), internal stresses, and deformations [8]. X-ray diffraction patterns show the transition from one structural modification to another, which manifests itself in the mixing of X-ray peaks. The results of calculations of the crystallinity index of samples of cellulose and MCC of amaranth and milk thistle are shown in Table 2.

Table 2. Absorption band of cellulose samples from the stem of medicinal plants (data for calculating the crystallinity index.

Name stem	**Absorption band, υ, cm^{-1}**	
	Cellulose	**MCC**
Amaranth	1370.92	1369.47
	2921.7	2905.30
Milk thistle	1371.4	1370.4
	2921.7	2911.09
Tribulus	1370.2	1367.47
	2918.8	2907.23
Consolida	1375.45	1373.18
	2925.07	2919.77

To determine the degree of crystallinity of watermelon MCC by the method of small angle light scattering in three fields: 2θ = 15-16, 22-23 and 34°.
The degree of crystallinity of MCC was calculated using the modified Rulond formula [11] based on the X-ray diffraction pattern.

$$I_{krist} = (I_{umum} - I_{amorf}) / I_{umum} \times 100\ \% = \frac{(7{,}1-1{,}6)}{7{,}1x100} = 77.5\%$$

It is known [9] that the IR spectrum of cellulose is determined mainly by the absorption of three hydroxyl groups present in each glucopyranose unit. Due to the formation of hydrogen bonds between themselves, the oxygen atoms of the glucoside units and oxygen bridges, there are a number of stable crystalline supramolecular structures that are interconnected by amorphous regions of cellulose. Such a variety of configurations of the cellulose molecule causes a strong broadening of the absorption bands. On the spectra of all 2 samples of cellulose, the absorption maximum is identical and practically coincides. The broad band 3700–3100 cm–1 of the IR spectrum of cellulose is associated with stretching vibrations of hydroxyl groups, and hydrogen bonds are involved. IR absorption of free hydroxyl groups (3650-4000 cm–1) is observed only in the absence of aggregation in the gas phase or very dilute solutions to vibrations of OH groups.

Four of the five C–H stretching vibrations appear around 2921.7-2905.3 cm–1; this band is used as an internal standard, since it does not depend on the crystallinity of cellulose. Absorption bands at 1372 cm–1 are bending vibrations of CH groups. An increase in the peak of the band of samples of all 2 in the spectra of MCC, stretching vibrations of OH groups. Which indicates that they are included in stronger hydrogen bonds, i.e. an increase in the density of structural elements (crystallites) compared to the original pulp samples. The data for calculating the crystallinity index of the samples according to the method [5] and their absorption band are given in Table 2.

The crystallinity index of cellulose and the MCC of the samples were calculated from X-ray data [7], which relates the intensity of the reflex (peak of crystallinity) and the intensity of the minimum, and from the data of the IR spectrum. The ratio of optical densities D1370/D2900 was used to calculate the crystallinity index [5, 9]. It is known [9] that the bands at 1370.1374 cm–1 characterize the bending vibrations of the C–H and CH_2 bonds. The bands at 2945 and 2853 cm–1 characterize, respectively, the asymmetric and symmetric stretching vibrations of the methylene groups. The band at 2900 cm–1 (vs-n) is used as a comparison. Table 3 presents the results of calculations of the crystallinity indices of these samples.

Table 3. Degree and index of crystallinity of cellulose and MCC obtained from amaranth and milk thistle.

Name		**Crystallinity index**	
Raw materials	**Sample**	**According to Sehgal**	**According to[5, 9]**
Amaranth	Cellulose	0.76	0.80
	MCC	0.81	0.95
Milk thistle	Cellulose	0.72	0.90
	MCC	0.84	0.95
Tribulus	Cellulose	0.74	0.85
	MCC	0.80	0.93
Consalida	Cellulose	0.70	0.87
	MCC	0.75	0.92

The crystallinity index of samples of cellulose and MCC of amaranth and milk thistle are close, their values are 0.76-0.72 and 0.81-0.84, respectively. The values of crystallinity indices calculated according to the method [5, 9] for amaranth cellulose are 0.80, and for milk thistle it is 0.10 units higher than for amaranth MCC. From the obtained MCC samples, tablets were made (Fig. 5), their technology and quality meet the pharmaceutical requirements.

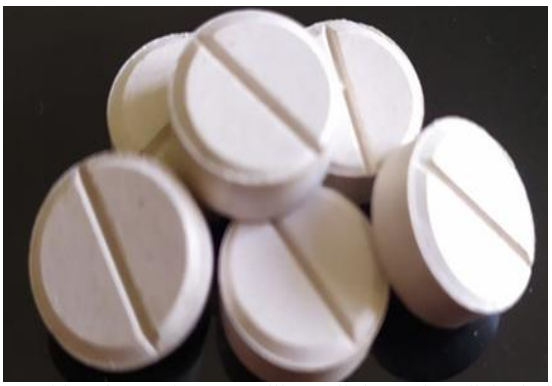

Fig. 5. Tablets from microcrystalline cellulose of medicinal plants.

4. Conclusions

Cellulose was isolated from the stems of medicinal plants of amaranth, milk thistle meal. Microcrystalline cellulose has been synthesized from celluloses. The structural features of celluloses and MCCs have been determined by physicochemical, IR spectroscopic, X-ray diffraction and microscopic methods.

Thickness of cellulose fibers is about 5 microns, and the length of crystalline particles is 20-30 microns.The length of milk thistle MCC crystallites is 2 times less (10-15 μm) than that of amaranth MCC. The degree of polymerization is in the range: cellulose 830-870, and MCC - 236 - 244. 0.84.

Tablets are made from microcrystalline cellulose according to standard technology and quality. Their tablet manufacturing technology meets pharmaceutical requirements.

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