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Applicability of Flax and Hemp as Raw Materials for Production of Cotton-like Fibres and Blended Yarns in Poland

Abstract
This paper contains a review of basic research and new concepts in flax and hemp fibre processing for flax and hemp cotton-like and wool-like yarns spun by different spinning systems. The review covers the trends and economical conditions since the beginning of the 20th century. We present the advantages and disadvantages of flax and hemp as raw materials for the production of cottonised fibres from the agricultural and economical point of view. Some significant morphological differences between flax and hemp are highlighted regarding the applicability of these fibres to the cottonisation process and spinning in blends with cotton by the pneumatic-mechanical spinning system. The content of mechanically obtained flax and hemp cottonised fibres in blends with cotton and the range of linear density of yarns is discussed. Examples of blended yarns with flax and hemp cottonised fibres applied in ready-made products are also presented.

Key words: *flax, hemp, cotton-like fibres, cottonised fibres, blended yarns, elementary fibres, production of blends, cotton, wool, polyester (PET), polyacrylonitril (PAN).*

Introduction

Poland has a rich and long tradition of cultivating and processing flax and hemp. The flax and hemp multi-cell fibre was processed into yarn according to traditional flax spinning technology [8, 9, 11, 12, 36, 37, 46]. The materials spun were technical flax and hemp long and short (two-type) fibre. The spinning was carried out by the wet (with possible boiling and bleaching of fibre) and the dry method. The flax spinning system, in comparison to other spinning systems such as the cotton or woollen system, is more labour-consuming and costly.

One possibility of more effective utilisation of flax and hemp in non-flax technologies is to adapt these fibres for spinning by modifying them by cottonisation, which yields cotton- or wool-like fibres. The first scientist who suggested utilising flax and hemp for cotton-like cottonised fibre in textiles was Prof. Bratkowski [5-7]. He justified his special interest in hemp and flax by the fact that these fibres were a domestic raw material of strategic importance for Poland, and they could (after certain modification) partially replace imported cotton. This opinion was stated at the beginning of the twentieth century. At that time Prof. Bratkowski was the initiator of innovative research conducted on manufacturing flax and hemp cottonised fibres and spinning it in blends with cotton. After the First World War, cotton spinning mills were very interested in cottonised fibres; they produced it on their own initiative, and added it to cotton blends. At that time, the state effectively supported the domestic flax industry through tax reductions for enterprises which used cottonised fibres. It should be emphasised that at that period, up to 40,000 tonnes of cottage-worked flax and hemp fibre was manufactured annually (cultivated on c. 100,000 ha) [36]. Most of the fibre was effectively exported abroad. Before 1939, attempts at hemp cotton-like cottonised fibres production were initiated in Italy [47]. The content of hemp cottonised fibres in these blends was 12.5-50%. The linear density of the yarns obtained was about 100 tex. However, the spinning process was more difficult when compared to pure cotton yarns; this resulted in lower efficiency of the spinning frames. The yarn also had lower tenacity in comparison to pure cotton yarn. Thus, the technology was not implemented commercially.

After the Second World War, the processing potential of flax and hemp increased considerably, due to the increase in their cultivation area up to 150,000 ha (60,000 tonnes of fibre yield) [12].

In traditional processing technology, flax was mainly used for thin yarns devoted to light fabrics (mainly shirts, underwear, tablecloths, curtains and clothes). On the other hand, hemp was mainly used for the production of thick yarns and technical fabrics (tarpaulins, twine, and farm string).

To increase the economics of flax and hemp utilisation, in the 1970s studies in applying these raw materials in non-flax processing technologies were initiated. Many experiments were carried out to manufacture and apply cottonised fibres in yarn blends produced by unconventional spinning technologies.

Efforts at utilising flax and hemp in different spinning systems and raw material compositions are documented in numerous publications. These studies were characterised by different ranges of flax and hemp content, and by scales of research, from laboratory and semi-technical to full industrial. Over time, these non-flax technologies were improved, the content of cotton- or wool-like fibre was increased, and the resulting yarns were thinner.

The studies were conducted by the Institute of Natural Fibres (previously the Institute of Domestic Natural Fibres) in Poznań, the Textile Research Institute in Łódź, the Technical University of Łódź, and the R&D Centre of Flax Industry in Żyrardów.

Over the last 20 years, many technologies have been developed for spinning and processing flax and hemp in blends with cotton, wool and chemical fibres. Unfortunately, due to the extremely unfavourable conditions of the textile industry restructuring over this period, especially since 1990, many companies were closed or had to reduce their production, among them companies processing flax and hemp cottonised fibres in blends.

Studies on Utilisation of Flax and Hemp in Woollen Spinning System

Woollen combing system

The first studies in Poland into the modification of flax for manufacturing wool-like cottonised fibres were carried out in 1972-1974, when garments made of natural fibres were very popular in domestic and international fashion. The fibre obtained was named Milen [38-40]. The tests were carried out with chemically modified flax biological noils. The modified (bleached) fibre in the form of slivers was processed in blends with wool or chemical fibres by the combing or carding woollen system.

The weaving yarns obtained in the carding system had a linear density of 32 tex and were available in the following compositions: 60% PET/35% flax, or wool 65% wool/35% flax. The blend linen 25% flax/25% PET/50% PAN was used for manufacture weaving and knitting yarns with a linear density of 32-36 tex. The results were implemented in the Polish companies Vigoprim, Tomtex and Norbelana, among others.

Broader research on the application of flax in spinning by woollen system was conducted using a wool-like fibre obtained by mechanical processing of dew-retted noils [13-16,18]. The trials yielded a wool-like fibre with an average fibre length of about 94 mm and a linear density of 2.3 tex, and were used for developing a spinning technology at the Merinotex Company in Toruń. The foundation of this new technology was the adaptation of a woollen carding machine for carding flax fibre blended with other fibres. This technology allowed commercial manufacture of the following knitting yarns: 30% flax/40% wool/30% PAN with a linear density of (42-62)x2 tex, and 15% flax/85% PAN with a linear density of 32x2 tex. Some of the new knitting yarn assortments were introduced into the production programme of the TPCz Merinotex spinning mill. The quality and utility features of these yarns were confirmed by the customers.

The trials were conducted [30] over the period from 1990 to 2000 in order to investigate manufacturing thin hemp/PAN yarns made by the woollen system, and were focused on modifying hemp fibres for processing by the woollen system. Methods for mixing components and further technologies for manufacturing blended yarns were included. The composition was 20% hemp/80% PAN; the linear density ranged between 32 tex and 64 tex.

Flax cottonised fibre was also used for spinning biological, enzyme-treated noils by the woollen system, according to a method developed at the Institute of Natural Fibres. The resulting yarn was composed of 50% linen and 50% wool, with a linear density of 32 tex [42,44].

Woollen carding system

The woollen carding system was used for the production of blended yarns with a linear density of 84-134 tex [38-40]. For the investigation ‘Milen’ yarn was used; this is a cottonised wool-like flax, chemically processed. The spinning trials were conducted at the Bardowski company in Łódź.

The first trials on spinning wool-like cottonised fibres were conducted by the woollen carding spinning system [10, 17, 20]. The one-type hemp fibre and modified dew-retted hemp noils were used for the trials. The modification of noils included variants of single and repeated processing by a tearing machine. The cottonised fibre was manufactured mechanically. The average length of the fibre obtained was 70-100 mm, at a very high linear density of 4.57-4.76 tex.

The manufactured blend of 40% hemp, 30% wool and 30% PAN had a linear density of 64-150 tex. Because the hemp fibre was very thick, the yarn parameters were unsatisfactory. However, these were the first trials in Poland with such material (a relatively high content of wool-like cottonised hemp fibre together with wool and PAN). The spinning trials were carried out at the Polska Wełna SA Company in Zielona Góra.

Studies into Using Flax and Hemp in Classical Cotton Spinning System

The impulse for studies on the use of flax in the cotton spinning system was the relatively large stock of low quality existing in domestic production in the 1980s a couple of thousand tonnes annually of Ns2 and Ns4 tow. The question arose of how to use this material most effectively. This fibre, which was heavily contaminated with shive, required intensive cleaning. After many trials, a contamination level was achieved which finally allowed spinning in blends with chemical fibres by the cotton spinning system [1-4]. This fibre was called ‘pakulen’. The ‘pakulen’ technology was implemented in the Włóknolen retting plant in Lębork. The ‘pakulen’ fibre was used for manufacturing blended yarn with a linear density of 40 tex, containing 40% ‘pakulen’ and 60% PAN.

Research was also conducted into applying mechanically obtained, cotton-like flax cottonised fibres in the ZPDz Sigmatex cotton mill in Piotrków Trybunalski [41]. The material for these tests was Ns10 and Ns12 flax noils. The parameters of the cottonised fibres obtained were as follows: length 25-35 mm, linear density 1.5-2.0 tex, impurities content 1.5%. It was found that in the Sigmatex conditions, it was possible to produce three-component blended yarns containing 20% linen, 50% cotton, and 30% PET. The best spinning performance was at linear densities of 25 and 30 tex. The company manufactured a cotton-like yarn with a maximum linen content of 20%. Any higher flax content caused technological problems in ring spinning.

Tests aimed at establishing the impact of the physical and chemical modification of flax fibre on the quality of cottonised fibres were also conducted [11, 21, 26-29, 31]. Yarns containing 20% and 50% of cottonised, cotton-like flax fibre were manufactured on laboratory scale for comparison.

Studies on Utilising Flax and Hemp in Cotton Rotor Spinning

Textile R&D centres have been interested in spinning flax and hemp in blends with cotton and chemical fibres by the rotor system since 1997 [19, 22, 23, 28, 32-34]. The following advantages of pneumatic mechanical (rotor) spinning were considered:

- the high speed of the spinning frame,
- additional defibration of flax and hemp fibre by spinning frame head drums,
- feeding the spinning frame with sliver and forming cross reels of yarn on a spinning frame (elimination of additional yarn reeling).

At that time, the studies on cottonised fibres were conducted with both flax and hemp fibre. The basic raw material for cottonised fibres production was dew-retted flax and hemp noils; in some cases it was flax dew-retted tow [31].

The hemp fibre was obtained from dual-purpose cultivation (for seed and for fibre). Comparison trials were also conducted, in which specially prepared one-type fibre from hemp cultivated for fibre was used [21,52]. For production of cotton-like cottonised flax and hemp fibre, the mechanical cottonisation process was mostly used.

The main aim of the studies was to produce the cheapest and the thinnest possible cottonised fibre, allowing yarn to be obtained with the lowest possible linear density and a high content of flax or hemp in the blend.

As a result of several years' production of flax and hemp cottonised fibres, as well as the improvement of the rotor-spinning system in Zamatex, the commercial production of yarn over a wide spectrum of linear density was initiated in co-operation with the Institute of Natural Fibres [23-25]. The scope of cotton-like blended flax and hemp yarns produced in the rotor system, as well as the fabrics made of these yarns, are discussed below in greater detail.

Studies on Application of Enzyme-treated Flax Fibre in Friction Spinning

A commercial technology for a new biological method of flax cottonisation was developed and implemented in 1997-1998 [42,44]. The flax cottonised fibre obtained by the enzymatic hydrolysis of flax noils and tow shows an altered fibre structure, high divisibility and physical and chemical properties which give the fibre resilience and a soft, silky feel, and permits the use of flax fibre for highly effective core (multi-layer) yarn production by the friction spinning system on Dref spinning machines [42,43]. The thickness of the core and the kind of raw materials used for the yarn components determined the flax fibres' content of 50-92%, and a linear density of 90-130 tex.

Differences in Anatomical Structure between Flax and Hemp

Both flax and hemp, unlike cotton or wool, are poly-cell fibres. Flax and hemp are treated as technical fibres in traditional spinning [49-51]. The possibility of dividing technical fibres into thinner aggregates of elementary fibres allows flax and hemp to be used for the production of cotton-like or wool-like fibres, as well as their application in blends manufactured by unconventional (non-flax) technologies. The most important parameters of flax, hemp and cotton are presented in Table 1. The distribution of fibres in a stem and the shape of elementary fibres and aggregates are presented in Figure 1.

Flax fibre forms strands in a stem, and is composed of elementary fibres joined together with the so-called middle lamellae containing mostly water-soluble pectin. These fibres form aggregates (bundles, clusters). The bundles are aggregated in larger units (the technical fibres), which are joined together with side joints (the anastomosises). The structure of hemp fibres is similar.

The elementary fibres of flax and hemp are similar to cotton regarding their length and thickness (Table 1). They have a spindle-like shape and a polygonal (mostly pentagonal) cross-section, with a channel (lumen) inside the elementary fibre. The cotton fibre is substantially different; it looks like a slightly twisted strand, which gives cotton better spinnability.

According to numerous studies, the division of technical hemp fibres into aggregates of elementary fibres for cotton-like cottonised fibres is more difficult than in the case of flax fibres, especially when the mechanical processing of fibres is concerned.

One unfavourable factor in the structure of hemp is the high content of lignin (Table 1). Lignin, like pectin, creates mechanical incrustations in sections of the amorphic cellulose, which contribute

Table 1. *Characteristics of features and properties of some plant fibres.*

Parameter	Unit	Flax	Hemp	Cotton
Length of technical fibres	cm	20 - 140 (av. 50)	80 - 300 (av. 120)	-
Length of elementary fibres	mm	1 - 130 (av. 13-40)	5 - 55 (av. 15-25)	10 - 70 (av. 12-36)
Fibre strength	G/tex	av. 53	av. 57	av. 30
Linear density of technical fibres	tex	av. 2	av. 2.2	-
Linear density of elementary fibres	militex	av. 290	av. 33	av. 200-143
Content of pectin in hemicellulose	%	19	17	-
Content of lignin	%	0.6 - 5.0	3.5 - 5.5	-
Content of water soluble compounds	%	4.3 (retted flax)	2.3	1.1

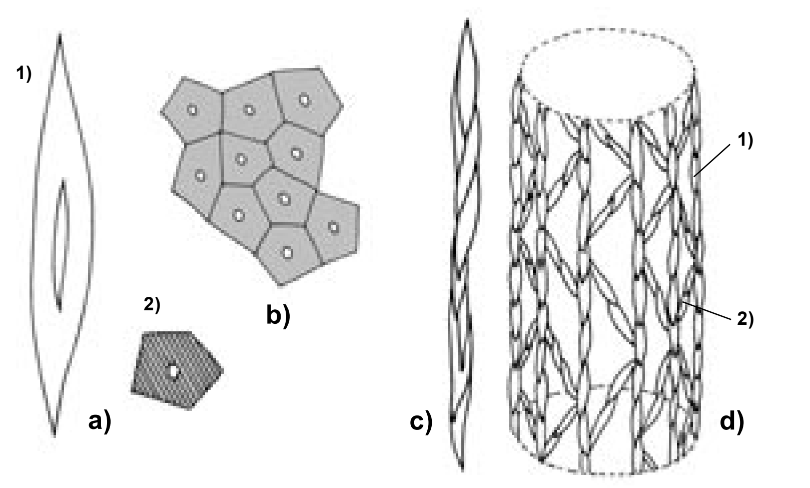

Figure 1. *Structure and distribution of elementary fibres of flax in a stem; a) shape of elementary fibre, 1 - longitudinal vie, 2 - cross-section; b) elementary fibre joint, middle lamellae: 20-25 elementary fibres in a bundle; c) aggregation of elementary fibres in a technical fibre; d) distribution of fibres in a stem, 1 - technical fibres, 2 - side joints (anastomosis), upper part of stem: 150-300 elementary fibres, middle part: 800-900 elementary fibres, lower part: 100-150 elementary fibres.*

Table 2. Yields of flax and hemp.

Output of:	Yield, tons/1ha	
	Flax	Hemp grown for seed and fibre
Raw straw	5.0	9.0
Dew-retted straw	4.0	6.7
Dew-retted fibre	1.12	2.0

to fibre lignification. Additionally, lignin is also often found in the middle lamellae which join the elementary fibres. The presence of lignin in both the elementary fibre and in the inter-fibre layers of technical fibre makes the fibre stiffer, more breakable, and reduces its divisibility and spinnability.

In especially undesirable feature of hemp is the presence of secondary fibre. This occurs mostly in the bottom of the stem up to the middle part, where it accompanies the primary fibre. The 40% content of secondary fibre is admissible for hemp fibre suitable for strings (III class) according to standards. The secondary fibre is generally shorter, thicker, more strongly joined together, and more brittle than the primary fibre, and is not suitable for spinning.

The root part of the scutched fibre is cut or torn off in traditional hemp spinning technology. Commonly practised hemp growing yields fibres of 8.5-6.6 tex, both for fibre and seeds. Flax fibres have a much lower linear density of 3.3-1.4 tex. This is the result of a substantial difference in the morphological structures of flax and hemp. The optimum thickness of a flax stem is 0.8-1.2 mm, and its length 0.5-1.2 m. In the case of hemp, the purpose of cultivation (for seed and fibre and for fibre exclusively) has a significant effect on the fibre quality, as it determines the morphological characteristics of the stem. The dimensions of hemp stem vary, depending on the purpose of cultivation: cultivation for seed and fibre: length 3-4.5 m, thickness 6-20 mm; cultivation for fibre only: length 1.5-1.8 m, thickness 4-6 mm. It should be emphasised that the secondary fibre occurs to a similar degree in thickness classes of 2-4 and 4-6 mm. In the 6-8 mm class, the secondary fibre occurs at a considerable length of the stem, which decreases the spinning properties and economics of the hemp fibre's production. According to [8], 'proper hemp' can ensure high thinness of elementary fibres at a level of 1.25-0.12 tex; for flax, this range is 0.67-0.1 tex.

Advantages and Disadvantages of Flax and Hemp from the Agricultural and Economical Points of View

Farmers' interest in growing flax and hemp is determined by the possibility of selling straw, seed and fibre, and the income they can make from that. The profitability of crops is determined by yields and prices, the latter being highly dependent on the market's price trend [37,50,52].

The output of straw, seed and fibre per area unit is much higher for hemp than for flax. However, flax is a fibre that can be more effectively used in the textile industry. Hemp is mostly used for the production of thicker fabrics and technical yarns. Both hemp and flax represent textiles of high usability and ecological qualities [35,45,48], such as:
- aseptic properties (bacteria and fungi static),
- good absorption,
- properties beneficial for human physiology (hygroscopicity, thermal insulation and anti-electrostatic features),
- protection against UV radiation (especially hemp), and
- lack of allergenic effects.

Due to these properties, flax and hemp should have a firm position among the textiles manufactured by both traditional and unconventional systems in blends with other textile raw materials.

In cultivation, hemp has many advantages in Polish conditions, in comparison to flax:
- it ensures relatively high yields,
- the producer's risk is smaller, provides more reliable yields,
- it improves the soil structure,
- it is an excellent for crop for flax, wheat, barley and root crops,
- diseases, pests and weeds pose much less of a threat to it.

Determining the Applicability of Some Types of Flax and Hemp Fibre for the Production of Cottonised Fibres

Traditional processing of flax dew-retted straw yields long scutched fibre and short fibre (tow). The long scutched fibre is then hackled, which yields a long hackled fibre and a short fibre (noils). Similar processes apply to the hemp dew-retted fibre obtained from common cultivation for seed and fibre. The processes (as for flax) yield long scutched fibre and short fibre (tow) [49,50]. Long hemp fibre undergoes an additional processing which is not done for flax: cutting or tearing off the fibre's ends in order to eliminate the secondary fibre and adjust the fibre to the length required in the hackling process. Removing the ends of the fibre yields a short fibre, called 'ends'. In the hackling of long scutched fibre, the fibre is divided into a long hackled fibre and a short fibre (noils). The qualitative output of the particular kinds of fibres obtained by the traditional processing technology is shown in Table 3.

Among the types of flax and hemp fibres mentioned above, practically only noils are used for cottonised fibre production. This is a fibre from the middle part of the stem, characterised by a high degree of divisibility and high purity (traces of shive).

Experiments showed that hemp which is cultivated only for fibre ensures that the parameters of the resulting cottonised fibres come close to those of flax cottonised fibres. The initial raw material for this production can be a one-type fibre

Table 3. Output of particular types of flax and hemp fibres from 1 t of dew-retted straw; percentages of the individual fibre types in relation to the total output are given in brackets.

Parameter		Flax		Hemp grown for seed and fibre		
		after turbo-processing of straw	after hackling scutched fibres	after turbo-processing of straw	after ends cut-off	after hackling scutched fibres
Total output of fibre, kg		280 (100%)	-	300 (100%)	-	-
Output of long fibre, kg	scutched	140 (50%)	-	225 (75%)	-	-
	scutched after ends cut-off	-	-	-	144 (48%)	-
	hackled	-	75.6 (27%)	-	-	60.5 (20.2%)
Output of short fibre, kg	noils	-	60.2 (21.5%)	-	-	77.8 (25.8%)
	tow	140 (50%)	-	75 (25%)	-	-
	ends	-	-	-	72 (24%)	-

or noils from the traditional technology of straw and scutched fibre processing. However, this requires the planting of specialised plantations. It should be emphasised that 1 ha of crop can yield approx. 240 kg of flax noils, and approx. 520 kg of hemp noils (hemp cultivated for seed and fibre). These raw materials are used to obtain mechanically produced cottonised fibres with parameters as shown in Table 4. It is possible to obtain thinner cottonised fibres by using chemical or enzymatic processing. However, these are laborious and costly treatments, which decrease the effectiveness of flax and hemp cottonisation.

Application of Flax and Hemp Cottonised Fibres in Blends with Cotton

An interesting contribution to the investigations carried out is the application of yarn with cottonised flax and hemp, and products made of them, in industrial production. Studies conducted jointly by the Institute of Natural Fibres and Zamatex allowed the production of following yarns (manufactured in fully commercial scale and conditions) to be implemented in 'Zamatex', by using the pneumatic-mechanical spinning system:

- yarns with flax content 40% (30 and 40 tex); 54% (50, 60, 80,and 100 tex).
- yarns with hemp content 54% (50, 64, 80, 100, and 120 tex).

Examples of utilisation of blended cotton-like yarns produced by the pneumo-mechanical system are listed below:

- TEXAS apparel fabric in natural colour with aerial density of 400 g/m^2; warp - 40x2 tex, 54% linen; weft - 100 tex, 42-54% hemp.
- TEXAS apparel fabric, bleached with aerial density of 400 g/m^2; warp - 40x2 tex, 54% linen; weft - 100 tex, 42-54% hemp.
- FILIP apparel fabric in natural colour with aerial density of 440 g/m^2; warp - 50x2 tex, 54% linen; weft - 100 tex, 42.2-54% hemp.
- Bed linen fabric with aerial density of 160 g/m^2; yarn - 40 tex, 40% linen.
- Knitted underwear fabric (double needle-bed knitted) in natural colour, finished with aerial density of 273 g/m^2; paraffin yarn - 50 tex, 40% hemp.
- Knitted dress fabric (V-bed knitted) with aerial density of 230 g/m^2; yarn - 40 tex, 44% linen.
- Sport socks, yarn 60 tex - 54% linen.

Summary

Interest in flax and hemp as raw materials for producing yarns by non-linen spinning systems in blends with other fibres has been noted in Poland for over 100 years. The ability of flax and hemp technical fibres to divide by mechanical, chemical or enzymatic treatments, enable manufacturers to achieve properties which allow spinning in blends with cotton, wool and chemical fibres by different non-flax spinning systems.

Due to the significant differences in structure between flax and hemp, the latter (grown for seed and fibre) is a much more difficult raw material for producing cotton-like fibre, especially by mechanical fibre division processing of the technical fibres.

Among the unfavourable factors characterising hemp as a textile raw material are the following: its higher content of lignin causing lignification of fibres, the higher occurrence of lignin in the middle lamella as compared to flax, the occurrence of secondary fibre (not suitable for cottonised fibre production) in the bottom part of the stem, and its considerably lower content of water-soluble compounds.

The fibre obtained from hemp grown only for fibre has a structure and parameters similar to flax fibre.

In cultivation, hemp is more attractive for a farmer than flax, and bears lower risk of losing the crop. It ensures higher yields, and has a beneficial effect on the soil structure. The cultivation of hemp is less laborious.

The cottonised, cotton-like, mechanically obtained flax and hemp fibres are currently used commercially in Poland for spinning yarns by the cotton rotor system at Zamatex and other companies. These fibres are used in high contents (40-54%) in blends with wool for producing 30-120 tex yarns, which are also used for production of garment, bed-linen, and underwear woven fabrics, as well as sport sock-knittings.

Conclusions

It seems advisable to undertake attempts at re-activating the Polish flax and hemp industry, especially of those Polish enterprises which manufactured flax and hemp fibres in Poland, and which limited their production as a result of the restructuring of domestic economic policy.

Table 4. Parameters of flax and hemp cottonised fibres.

Kind of fibre	Fibre length, mm	Linear density of fibre Tt, tex
Flax cottonised fibres	18 - 35	1.20 - 2.0
Hemp cottonised fibres (from hemp grown for seed and fibre)	20 - 32	1.46 - 2.3

Considering the current structure of flax and hemp cultivation (for seed and fibre) in Poland, the most suitable fibres for manufacturing mechanical cottonised fibres are hemp and flax noils. They are highly divided and clean, and are currently the main commodity traded between spinning mills and processors which produce carding yarns (in the traditional system) and blended yarns with cottonised fibres (in the unconventional system).

The cottonised fibre obtained from flax fibre is usually thinner than that of hemp, which allows yarns with lower linear density to be obtained. It is possible to obtain thinner hemp cottonised fibre by a one-type system from hemp grown only for fibre, as was confirmed by the studies cited, but the cultivation of hemp for fibre only is not practiced in Poland. Implementing this idea needs an agreement between farmers, hemp fibre producers and producers of cotton-like cottonised fibres.

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