An explorative study of the potential substitution of cotton textile materials by equivalent hemp fabrics -

Potential optimization of the basic characteristics of cellulose textile materials by means of liquid ammonia treatment

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Abstract

Cellulose textile fibers like cotton and viscose are widespread used for a vast number of textile applications. The ecological footprint of their all-in production profile however, is opening ways towards alternative options like hemp. This publication offers an insight into the efficiency and usefulness of hemp clothing. This is based on a first generalization of test results, obtained after a preliminary screening of the basic physical characteristics of hemp tissue types in comparison with those of equivalent cotton tissues. Comfort management evaluation reveals the true potential. Besides, liquid ammonia treatment has been explored as a possible optimization route for upgrading the initially found physical parameters. In this, normalized methods have been deployed across the performed research to ensure a scientific approach.

Introduction

Hemp fibres are gaining rising interest as potential durable alternative for the widespread usage of cotton and flax fibres. For the cultivation and processing of 1 kg of cotton 10.000 l water is requested (Cherrett et al.). Moreover, 16% of the worldwide pesticide consumption is due to the cultivation of cotton. The appealing cultivation characteristics of the hemp plant (Cannabis sativa) are various: substantial lower water consumption level during growth in comparison with cotton, limited/no need for pesticides, high fibre yield rates (short vs long fibres), purification of (contaminated) soil, local fibre cultivation, etc. Different parts of hemp plants are multivariable applicable: hemp shives in shed beddings and panels, medicinal (THC/CBD), hemp seeds, hemp oil, textile fibre source,… Adapted fibre extraction methods have to be applied during processing. Moreover, due to a high content of natural impurities and the technical composition of the hemp fibre (i.e. a lignin/fibre matrix), adapted pretreatment schemes have to be explored. Clear parallels with flax can be distinguished into this approach.

Hemp4All, a running, 2-year TETRA project at FTI Lab (2018-2019), aims to explore the potential of alternative/biochemical (read: enzymatic driven) pretreatment routes (scouring vs bleaching) for raw hemp materials. This publication focuses onto a number of other project objectives: a) the validation of hemp materials as a valuable option for the creation of casual and workwear; b) a screening of essential comfort parameters of hemp textiles; c) impact of liquid ammonia treatment onto hemp fabrics.

1. Scan of the physical properties of hemp tissues – a comparison with cotton

A pragmatical approach has been developed to compare essential physical properties of hemp versus cotton tissues. 100% hemp tissues and mixtures with organic cotton or recycled polyester have been selected. The tested fabrics are:

- Hemp tissue: bleached; undyed; plain weave; 207 g/m² (@Libeco-Lagae - B)
- Hemp tissue: dyed (green); plain weave; 147 g/m² (@Ecological Textiles – NL)
- Hemp / organic cotton tissue 55/45: dyed (blue); twill; 324 g/m² (@Ecological Textiles – NL)
- Hemp / polyester tissue 55/45: bleached; undyed; twill; 278 g/m² (@Ecological Textiles – NL)
- Cotton tissue: bleached; undyed; Panama bond; 250 g/m² (@Concordia Textiles – B)
- Cotton tissue: dyed (blue); twill; 320 g/m² (@Utexbel – B)

Determination of the essential, physical characteristics of the above mentioned tissue types is done based on the test matrix presented in table 1.

Table 1: Physical test protocol

Physical parameter	**Norm**
Tensile strength / strain	Strip method cfr. ISO 13934-1
Tear strength	Elmendorf cfr. ISO 13937-1
Abrasion resistance	Martindale cfr. ISO 12947
Pilling (tissue – tissue)	Modified Martindale method cfr. ISO 12945-2
Crease susceptibility	a) Wrinkle recovery test cfr. AATCC Test method 128 b) Smoothness after industrial (cfr. ISO 15797 - 60°C) washing cfr. ISO 7768 c) Decreasing angle (dry) cfr. ISO 2313-1
Dimensional stability after industrial washing (cfr. ISO 15797 - 60°C)	Preparation cfr. ISO 3759; shrinkage determination cfr. ISO 5077
Seam slippage	ISO 13936-2 (fixed load method: 60 N / 120 N)
Tactility - hand – touche[1]	Fabric Touch tester (FTT @SDL Atlas) - no existing norm
Moisture management[2]	Moisture Management Tester (MMT @SDL Atlas) cfr. AATCC Test method 195

Remarks

[1] *Fabric Touch Tester* (FTT @SDL Atlas) is an all in one test unit for objective evaluation of the hand of various textile materials. It's a further optimization of the well-known Kawabata Evaluation System (KES). Analysis is based onto the determination of the following physical properties: bending stiffness, compression behavior, geometrical roughness, friction, heat flux. Out of this determining, primary hand indices are derived: softness, smoothness, warmness, total hand. Each index is going from "0" (= lowest score) to "5" (= maximal score). Each time, average values of upper and inner substrate sides are reported.

[2] *Moisture Management Tester* (MMT @SDL Atlas) evaluates 6 hydrophilicity indicators, namely wetting time, absorption speed, wetting radius, spreading rate, one way transport index, overall moisture management capability. Each indicator scores between 1 (= lowest) and 5 (= highest hydrophilic property). Into this research, the hydrophilic character of the textile sample is reported as an average value of the 6 individual scores, where each parameter has the same weight.

Table 2: Physical properties of hemp and cotton tissues – test values

	Hemp tissue - bleached	Hemp tissue - dyed (green)	Hemp/organic cotton tissue 55/45	Hemp / polyester tissue 55/45	Cotton tissue - bleached
Weight	**207 g/m²**	**147 g/m²**	**324 g/m²**	**278 g/m²**	**250 g/m²**
Tensile strength / strain - warp	**659,05N/11,54%**	**371,17N/12,77%**	**1136,25N/28,18%**	**1620,02N/16,64%**	**840,61N/10,01%**
Tensile strength / strain - weft	**648,31N/8,96%**	**284,32N/11,32%**	**626,21N/10,60%**	**665,72N/12,96%**	**825,62N/10,08%**
Tear strength - warp	**47,01N**	**34,52N**	**71,88N**	**43,74N**	**27,62N**
Tear strength - weft	**53,99N**	**34,38N**	**83,82N**	**64,16N**	**29,07N**
Abrasion resistance	**4000 turns**	**2000 turns**	**18000 turns**	**35000 turns**	**15000 turns**
Average weight loss at break	**-9,22%**	**-18,94%**	**-7,69%**	**-8,57%**	**-9,22%**
Pilling - Martindale (2000 tr)	**1**	**2/3**	**3**	**3**	**4/5**
Crease susceptibility:					
a) Wrinkle recovery test	**1/2**	**1/2**	**3**	**2**	**1/2**
b) Smoothness after:					
--> 1 * industrial washing à 60°C	**2/3**	**4**	**3/4**	**3**	**1**
--> 5 * industrial washing à 60°C	**2**	**4**	**4**	**2/3**	**2/3**
c) Decreasing angle - warp	**64,25°**	**65,75°**	**73°**	**61,75°**	**59,75°**
Decreasing angle - weft	**65,25°**	**68,50°**	**68,75°**	**87,50°**	**67,50°**
Dimensional stability - warp					
--> 1 * industrial washing à 60°C	**-5,2%**	**+0,5%**	**-4,0%**	**-6,3%**	**-4%**
--> 5 * industrial washing à 60°C	**-5,8%**	**-1,3%**	**-3,0%**	**-3,8%**	**-5%**
Dimensional stability - weft					
--> 1 * industrial washing à 60°C	**-2,0%**	**+2,1%**	**-1,5%**	**0,0%**	**-5%**
--> 5 * industrial washing à 60°C	**-3,3%**	**+2,5%**	**-3,0%**	**0,0%**	**-5,8%**
Seam slippage - warp	**1,7 mm**	**3,6 mm**	**1,7 mm**	**1,1 mm**	**1,3 mm**
Seam slippage - weft	**1,8 mm**	**3,7 mm**	**1,3 mm**	**1,1 mm**	**1,3 mm**

Table 2 offers an overview of values obtained after performing the earlier stated physical test protocol. The main observations are:

- Hemp tissues can offer essential, mechanical properties within marketproof margins for casual and workwear. For instance tensile strength scores > 600 N; tear strength levels > 20 N (both warp and weft direction)
- The tested 100% hemp tissues show limitations on behalf of abrasion resistance, pilling tendency and susceptibility to crease formation.
- The drawbacks of pure hemp can be (partially) overcome by means of application of intimate yarn mixtures e.g. hemp/organic cotton or hemp/recycled polyester. By doing so, a boost is noticed in terms of substantially higher tensile and tear strength values, (nearly) acceptable abrasion resistance levels (i.e. > 20.000 cycles cfr. ECLA), less pilling and crease formation.
- Only in case of the low weight, green hemp tissue an acceptable seam slippage limit value of 3 mm (cfr. jeans) has been exceeded.
- Concerning dimensional stability during industrial washing à 60°C, hold maximal deformation limits are normally within +/- 2%. None of the tested substrates reaches this level in both directions (warp, weft).

Figure 1 offers an overview of the hand characteristics of the tested cotton and hemp tissues based on FTT analysis. Only smaller differences in the individual, primary hand indices can be distinguished. Indeed, all tissues consist of staple (cotton, polyester) or technical (hemp) fibres.

Variation in smoothness (ranging from 2,5 to 3,5) can be due to singeing or shaving processes, typically performed onto hemp tissues. Differences in fabric construction (binding pattern, lower weight) provokes aberration in binding stiffness and flexibility, resulting into higher softness grades (cfr. low weight 100% hemp tissues). The main observation is formed by the fact that the application of hemp fibres in tissue form at least results into touche levels reached by equivalent cotton fabrics.

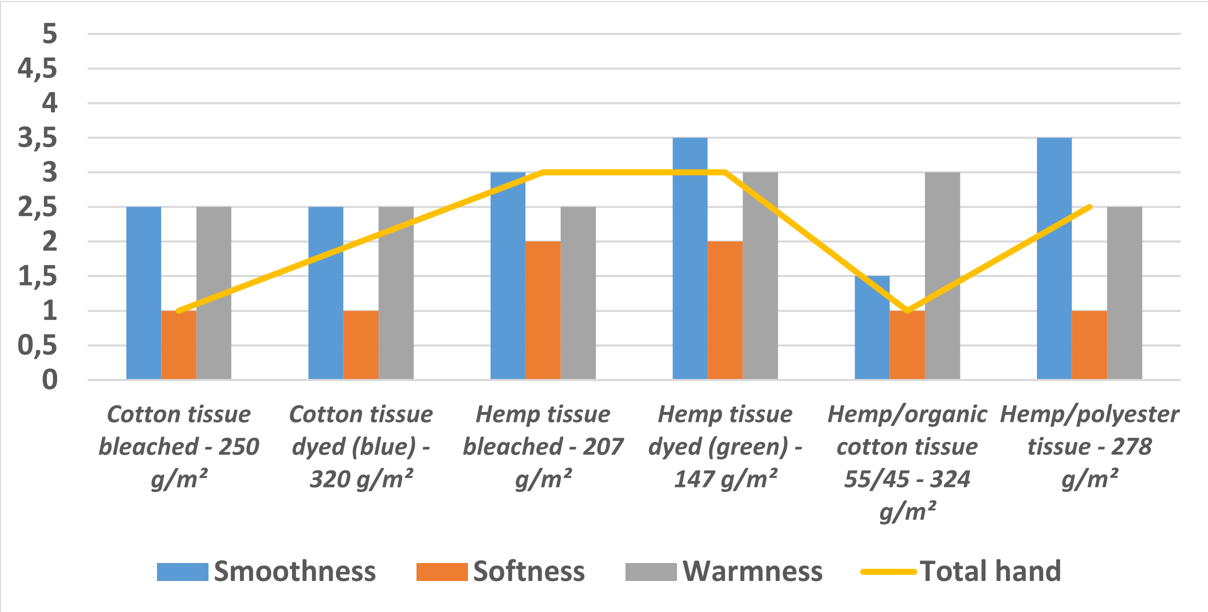

Figure 1: Tactility analysis: hemp versus cotton tissue

Further improvement of the hand characteristics of hemp materials can be induced by tumbling or stonewash[1] treatments. This last technique is often applied as a final finishing step, whereby abradants are opening the fibre structure. This – whether or not in combination with softeners – leads to a substantial softer end product.

2. Impact of liquid ammonia treatment onto cellulosics

Overall optimization of the physical parameters of cotton and hemp textiles is possible via substrate finishing with e.g. anti-crease, softening and/or anti-pilling agents. The add on of these synthetic polymer systems however conflicts with the 100% natural state of the basic materials. A zero deposition modification methodology like liquid ammonia (NH_3) treatment overcomes this problemacy, leading to a maximal degree of recyclability at the end of the product's (first) life cycle. Moreover, potential unwanted release of chemical finishes during usage and/or cleaning of the textile product is avoided (lower ecological footprint).

Liquid ammonia treatment can be done under subcontracting at Veramtex (B – Beau-Fixe® process). The treatment scheme is presented in figure 2 [1]. Step A stands for the substrate dipping into liquid ammonia (-33°C) at atmospheric pressure during less than 10 seconds. Steps B and C intend the complete ammonia removal afterwards over heat treatment (120°C) respectively rinsing in water (80°C). The last step (D) is formed by substrate drying on a stenter system. More than 99% of the applied ammonia is finally recovered by means of adequate distillation. The Beau-Fixe® treatment is Standard 100 and STeP by OEKO-TEX® certified, proving the ecological profile of the treatment.

[1] Stonewash: discontinuous treatment with limestone or pumice

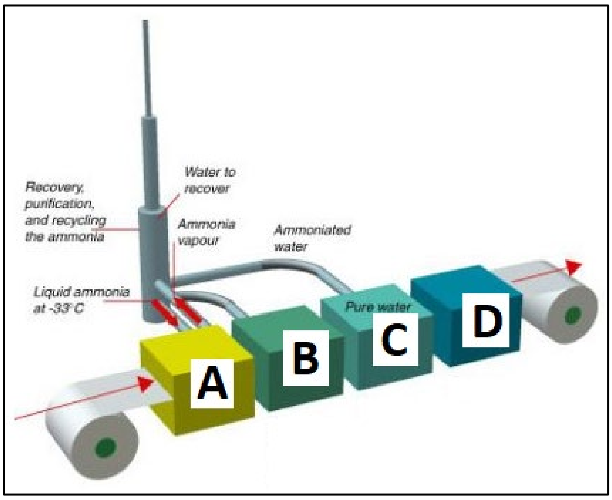

Figure 2: Beau-Fixe® process (Veramtex)

The impact of continuous ammonia treatment onto cellulosics (CO, CV, L) is highly comparable with mercerization[2]. The individual cotton fibers lose their typical torsions (up to 60 torsions/cm) while heavily swelling (see figure 3). Crystalline and semi-crystalline zones get permanently modified by this. The typical kidney shaped fiber cross section becomes rounder. The fiber structure in total (partially) loses its internal stress. Finally a stabilized material is formed. This leads to the following (theoretical) property improvements: higher dimensional stability, less crease formation, softer/voluminous touche, higher gloss aspect, rising dyeability, better mechanical properties (e.g. strength, abrasion resistance, pilling). A distinctive example is given in figure 4: nearly no shrinkage and crease formation is experienced after washing a test cotton tissue sample under the condition of ammonia pretreatment [1].

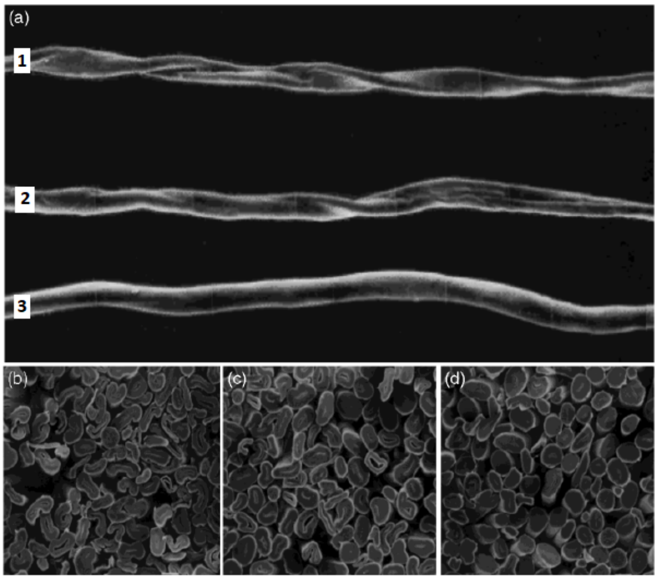

Figure 3: SEM-images: a) cotton fiber - 1 : bleached - 2: mercerized - 3: ammonia treated; b) cross section bleached cotton fiber; c) cross section mercerized cotton fiber; d) cross section ammonia treated cotton fiber [2]

[2] Mercerization: treatment of cellulose textile materials with highly concentrated alkaline solutions (100 – 300 g/l NaOH)

Figure 4: Positive impact of Beau-Fixe® treatment onto shape retention during washing

The potential positive influence of liquid ammonia treatment on the material properties of hemp textiles is mentioned in literature [3, 4, 5, 6]. This study aims to give a practical insight in the transferability of the Beau-Fixe® treatment from cellulose materials like cotton and flax towards hemp. The earlier mentioned physical test protocol (see table 1) has been worked out onto the bleached cotton and hemp tissue selection. Varying parameter in this is the eventual application of a standardized Beau-Fixe® treatment. Results are summarized in table 3.

Table 3: Impact of NH_3 treatment on physical properties of bleached cotton and hemp tissues

	Cotton tissue - bleached	**Cotton tissue - bleached & NH_3 treated**	**Hemp tissue - bleached**	**Hemp tissue - bleached & NH_3 treated**
Weight	250 g/m²	270 g/m²	207 g/m²	227 g/m²
Tensile strength / strain - warp	840,61N / 10,01%	956,50N / 8,74%	659,05N / 11,54%	864,19N / 7,35%
Tensile strength / strain - weft	825,62N / 10,08%	820,41N / 19,13%	648,31N / 8,96%	582,62N / 21,19%
Tear strength - warp	27,62N	35,03N	47,01N	50,77N
Tear strength - weft	29,07N	32,49N	53,99N	45,29N
Abrasion resistance	15000 tr	35000 tr	4000 tr	4000 tr
Average weight loss	-9,22%	-5,63%	-9,22%	-10,06%
Pilling - Martindale (2000 tr)	4/5	4/5	1	1
Crease susceptibility:				
a) Wrinkle recovery test	1/2	3	1/2	2
b) Smoothness after industrial washing				
*--> 1 * washing à 60°C*	1	2/3	2/3	2
*--> 5 * washing à 60°C*	2/3	3	2	2
c) Decreasing angle - warp	59,75°	79,25°	64,25°	65,50°
Decreasing angle - weft	67,50°	68,75°	65,25°	73°
Dimensional stability - warp				
*--> 1 * washing à 60°C*	-4%	0%	-5,2%	-4,1%
*--> 5 * washing à 60°C*	-5%	-2%	-5,8%	-5%
Dimensional stability - weft				
*--> 1 * washing à 60°C*	-5%	0%	-2%	+2,6%
*--> 5 * washing à 60°C*	-5,8%	-0,5%	-3,3%	+2,6%
Seam slippage - warp	1,3 mm	2,3 mm	1,7 mm	2,4 mm
Seam slippage - weft	1,3 mm	1,7 mm	1,8 mm	1,7 mm

Below, the main observations are described. The liquid ammonia process induces a higher substrate weight. This is owing to a substrate shrinkage during processing, only noticeable in the weft direction: a) cotton tissue: -8,10%; b) hemp tissue: -12,48%. In case of the bleached cotton tissue a significant upgrade of physical properties is attained after ammonia finishing: a) tensile strength in warp direction: +13,8%; b) abrasion resistance: 15000 turns → 35000 turns; c) less crease susceptibility; d) deformation after industrial washing ≤ 2%. Seam slippage values heighten (read: lower yarn slip resistance cfr. rounder fibre cross section), but are still below 3 mm (cfr. ECLA guidelines). FTT analysis reveals a completely similar haptic aspect before and after ammonia processing of the bleached cotton tissue. Substantial, mechanical features of the tested hemp tissue like abrasion resistance, pilling, crease behavior and form stability aren't positively influenced after NH_3 pretreatment. The modification of primary sensory indices (FTT) are divergent through NH_3: smoothness: 3 → 3,5; softness: 2 → 1; warmness: steady 2,5. This is negatively finalized in a total hand evolution from 3 to 2. Nevertheless, testing of heavier hemp tissue types (range: 300 - 650 g/m² - see figure 5) indicates the potential of Beau-Fixe® treatment of hemp textiles.

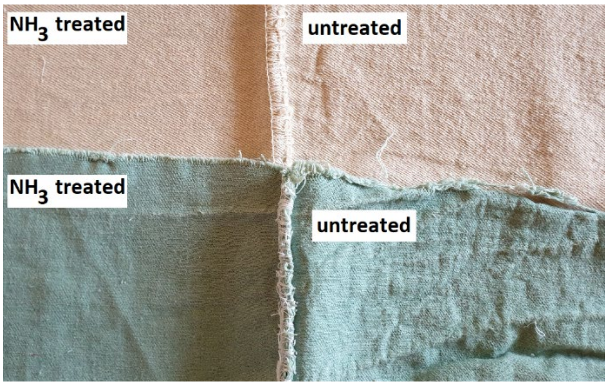

Figure 5: Heavy hemp canvas weave – fabric conservation during washing (60°C) via Beau-Fixe®

The effect of liquid ammonia finishing on the dyeability behavior is evaluated as follows. Three, distinctive dyeing processes are individually performed onto the bleached cotton and hemp tissues (each time one sample untreated, another NH_3 pretreated). The impact on dyeing efficiency is measured by determination of colorimetric values: a) K/S (Kubelka-Munk); b) L color coordinate (Lightness); c) delta E (color difference). The test matrix and obtained test values are proposed in table 4.

Table 4: Impact of Beau-Fixe® on dyeing characteristics of cotton and hemp materials

Discontinuous dyeing process with reactive dyestuff (deep, purple tint; trichromia)			
Substrate	**K/S value**	**L value**	**delta E**
Untreated bleached cotton tissue	**21,99**	**20,34**	**1,89**
NH_3 treated bleached cotton tissue	**25,95**	**18,90**	
Untreated bleached hemp tissue	**12,83**	**26,97**	**2,90**
NH_3 treated bleached hemp tissue	**16,43**	**24,53**	
Discontinuous dyeing process with reactive dyestuff (deep, yellow fluorescent tint; monochromia)			
Substrate	**K/S value**	**L value**	**delta E**
Untreated bleached cotton tissue	**13,65**	**99,47**	**2,23**
NH_3 treated bleached cotton tissue	**16,33**	**99,57**	
Untreated bleached hemp tissue	**7,79**	**96,37**	**4,01**
NH_3 treated bleached hemp tissue	**9,99**	**95,17**	

Discontinuous dyeing process with vat dyes (middle deep gray tint; trichromia)			
Substrate	**K/S value**	**L value**	**delta E**
Untreated bleached hemp tissue	**2,80**	**45,43**	**3,03**
NH_3 treated bleached hemp tissue	**3,43**	**42,47**	

All dyeing processes obtain a higher dyeing yield under the condition of NH_3 pretreatment: rising color depths are indicated by higher K/S and lower L values. Each time a for the human eye visible color difference (i.e. delta E > 1) is observed. Remarkably, for completely similar dyeing conditions a higher dyeing effect is noticed for the cotton tissue in comparison with the hemp tissue. This last one however shows the highest dyeing depth upgrade after liquid ammonia processing. Rubbing (dry/wet bleeding) and washing (bleeding vs degradation) fastness levels are determined over normalized tests: ISO 105-X12 respectively ISO 105-C06: C1M (60°C). Out of this can be concluded ammonia pretreatment doesn't influence the fastness properties of the dyed materials.

The basic hydrophilic character of bleached and/or dyed cotton and hemp tissue types is determined by means of a Moisture Management Testing system (for method description: see table 1, inclusive remark 2). Obtained, averaged results are given in table 5. The evaluated hemp tissues in pure and mixed form show a similar and good interaction with water (minimal degree of 3,05), comparable to that of equivalent, cotton tissues. This proves the potential usefulness of hemp fibers in application like (bath) towels, T-shirts, trousers, incontinence articles (e.g. diapers), handkerchiefs, mops, etc. Moreover, an adequate and steerable moisture management behavior is a crucial aspect in a broader comfort perception.
Beau-Fixe® treatment slightly lowers the initially measured hydrophilic level. An explanation can be found through analysis of the individual, moisture management indicators: NH_3 processing causes a limited decrease in wicking property.

Table 5: Hydrophilic property of cotton and hemp tissues – Impact of liquid ammonia treatment

Substrate	**Indicator hydrophilic character**
Cotton tissue - bleached	**4,3**
Cotton tissue - dyed (blue)	**3,2**
Hemp tissue - bleached	**3,05**
Hemp tissue - dyed (green)	**3,2**
Hemp/organic cotton tissue 55/45	**3,4**
Hemp/polyester tissue 55/45	**4,2**
Cotton tissue - bleached & NH_3 treated	**3,8**
Hemp tissue - bleached & NH_3 treated	**2,65**

Conclusions

Determining, physical properties like tensile strength/strain, tear strength, moisture management behavior and tactility aspect of hemp tissues reach similar or higher levels in comparison with equivalent, cotton materials. This substantiate the potential substitution of cotton and/or synthetic materials by means of hemp alternatives. However, referring to application fields as casual and workwear, parameters like pilling formation, dimensional stability (after industrial washing), crease susceptibility and/or abrasion resistance might request an upgrade. This sharply depends on the used type of hemp tissue. Possible optimization routes are given by a) use of fiber mixtures like hemp/organic cotton or hemp/(recycled) polyester; b) liquid ammonia pretreatment (Beau-Fixe® @Veramtex). This last, zero-depostion option renders additionally a substantially higher color depth after dyeing (with unchanged fastness properties).

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Keywords

Hemp, cotton, liquid ammonia, ecological, physical properties, testing, optimization

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