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Comparison of Selected Properties of Eco-Friendly Soybean and Other Fibres

Abstract
Biodegradable and sustainable products are being employed to make contributions to efforts concerning environmental protection and the reduction of oil consumption. Biodegradable fibres present a simple and notable opportunity for providing sustainable textiles. Soybean fibre is a kind of regenerated and new-generation protein plant fibre. The present work aimed to analyse the many different properties of soybean fibres. Particularly it was focused on their performance, functional, comfort and dyeing properties. In literature, there are studies regarding soybean fibres but topics mostly involved the analysis of comfort properties of the fibre. In this study, fibre structure and composition, flame and UV resistance, strength, pilling behaviour, air and water vapour permeability, water absorption, drape and dyeing properties were studied. It was indicated that soybean fibre is capable of meeting the performance, comfort and functional requirements of classical and technical textile products. The fibre has many of the good qualities of natural fibres such as tenacity, moisture regain, soft-lustrous handle, dyeability and colour fastness properties, and also has some of the functional properties of synthetic fibres such as being flame retardant and anti-ultraviolet.

Key words: *soybean fibre, regenerated fibre, dyeing properties, biodegradable fibre, sustainable products, functional properties, flame resistance. .*

Introduction

Soybean protein fibre (SPF) is the only plant protein fibre. It is a liquefied soy protein that is extruded from soybean after the extraction of oil, and processed mechanically to produce fibres using new bioengineering technology. Fibres are produced by wet spinning, and stabilized with acetylation, and finally cut into short pieces after curling and thermoforming [1]. Soybean fibre has been assessed as healthy and environmentally friendly textile fibre since raw materials used in manufacturing are very eco-friendly. In addition, the raw material comes from soybean, a plant of massive source and rich in nutrition. Therefore SPF is biodegradable and can go back to the earth [2]. SPF fibre particularly attracts attention with its appearance, being similar to silk fibres, with soft and smooth handle. It has a cashmere feel, but smoother [2 - 6]. The textile sector uses 100% soybean fibre and its blends with cotton as well as wool, cashmere and angora fibres etc. for the production of socks, t-shirts, baby clothes, towels, bath towels, bed textiles, underwear, shirts, suits, sheets etc. It was advised to use soybean fibre as a blend with cotton (50/50%), wool (50/50%) and cashmere (80/20%) fibres [5]. Particularly the smooth surface of SPF sometimes leads to low spinnability, and the surface structure and low cohesion force are some of the reasons for blending. Therefore it was stated that anti-slipping agent usage is necessary for the spinning [6]. Soybean fibre is also frequently blended with cotton fibres, being a natural fibre. Since soybean fibre resembles cotton fibre in its moisture conductivity, soybean fibres together with cotton ones will be compatible in blends.

In recent years, with increasing environmental awareness, the usage of renewable raw materials as well as eco-friendly and sustainable fibres has become very important. In addition, the production of many synthetic fibres pollutes the environment. Therefore it is necessary to give importance to new regenerated fibres. In literature, Vynias et al. [7] studied the effect of oxidative and oxidative-reductive bleaching on colorimetric, topographical and mechanical properties. Zupin and Dimitrovski [1] examined the mechanical properties of the fabrics produced from cotton and biodegradable yarns such as bamboo, soybean, and polylactic acid (PLA). They concluded that among fabrics woven in a plain weave, that with SPF yarn in the weft had the highest tensile strength, while SPF provides better strength than that of other fibres in the warp direction. Cimili et al. [8] studied comfort properties, while Ciukas and Abramaviciute [9] investigated the air permeability property of socks produced from soybean and other new kinds of fibre. They concluded that fibre type seems to markedly affect comfort properties. Kavusturan et al. [10] used comfort fibres like Tencel, bamboo, modal, soybean, 50/50% soybean-Tencel and conventional fibres like viscose and cotton for the production of chenille yarns. In the study, the influence of chenille yarn parameters like pile and core fibre type on fabric abrasion and bending behaviour was investigated. It was indicated that fabrics produced from chenille yarns of soybean and 50/50% soybean-Tencel blend pile fibres showed moderate abrasion resistance compared with the other types. In another work, Vynias [11] investigated the effect of N-methylol diakyl phosphonopropionamide (Pyrovatex CP) on the flame retardancy of soybean. With Pyrovatex CP and the incorporation of finishing treatment, the LOI (limit oxygen index) values of soybean fibre increase and improved fastness to washing was observed at a higher application. Marmaralı et al. [12] studied the thermal comfort properties of blended yarn knitted fabrics and indicated that the air permeability and thermal absorption increase as the amount of soybean and seacell fibres in the blend is increased. The fabrics give a cooler feeling. Örtlek and Korkmaz [13] investigated the abrasion and pilling resistance of fabrics produced from 100% soybean fibres and its mixtures with cotton. They indicated that soybean fibres have better resistances and superior handle and shining. Reddy and Yang [14] realised a simple alkaline extraction to obtain technical fibres from soybean straw and analysed the composition, structure and properties of the fibres. Soybean is very rich in proteins and composed of mainly amino acids [15, 16]. Contrary to common belief, Reddy and Yang [14] determined that soybean fibres have a similar cellulose content to cotton but relatively low crystallinity. Nevertheless the fibre shows good orientation of cellulose crystals along the fibre axis. The tenacity of the technical fibres is similar to that of cotton, and the elongation of the fibres is higher than that of common bast fibres but lower than that of cotton. They concluded that soybean straws have the properties required for textile, composite and other high value industrial applications.

According to studies in literature, soybean fibre is characterised with quick wet permeability and the moisture transmission function. Therefore, comparing to other features, the comfort properties of soybean fibres have been widely studied by many researchers. However, there are not any findings about other properties of soybean fibre. It is interesting that there are not so many published experimental data about the tensile properties of soybean yarn and fabrics by researchers. On the other hand, soybean fibre has been shown to have functional properties such as UV resistance, antibacterial activity, far infrared emissivity and negative oxy-anion release. The absorptivity of ultraviolet radiation and the restrain-bacterial function may help to protect the health, while the far infrared and negative oxy-anion functions promote the micro circulation of skin and enhance immunity. In addition, one of the outstanding properties of soybean fibre is its silk-like drape and lustre [3, 4, 6, 7, 16]. Nevertheless there have not been any researches focused on the analysis of these properties and findings published so far. Additionally the visual aesthetic properties of fabrics, especially colour, are also important as well as other properties. Although soybean fabrics are characterised by light colour and lustre as well as good sunlight resistance and perspiration fastness [3, 5, 16], there is not enough comprehensive information and results presented about the colour properties of knitted fabrics made from soybean fibres. In addition to the good colour properties of these fabrics, they also retain their original colour after being used for a certain length of time. As is already known, fabrics lose their colour under different conditions such as rubbing, washing, perspiration, exposure to sunlight, abrasion and so on. Therefore colour fastness properties are important to assess the colour durability of fabrics. The present work aimed to study some of the functional as well as performance and comfort properties of soybean fibre and its blends. In addition, this study also investigated the colour values and fastness properties of soybean fibres.

Material and method

In this study, 100% soybean, bleached soybean, bamboo (viscose-type) and cotton yarns, 80/20% soybean/cotton and soybean-angora yarns of 29.5 tex were used [17, 18], supplied by the Hayteks Ekolojik Textile company (Turkey). The fibre fineness of the soybean was 1.5 dtex and the fibre length 38 mm. In the present study, we also aimed to analyse the performance of soybean fibre blends as well as that of soybean fibre. Soybean fibre is a regenerated fibre, therefore we would like to compare soybean fibre properties with one of the popular regenerated fibres - bamboo, which has usage in similar textile products [4]. Therefore it will be possible to define the superiority of soybean fibre to bamboo fibre. Fabrics were knitted from the yarns on a sample sock knitting machine (Lonati 462). Fabric productions were realized on the same knitting machine with the same loop density.

Scanning electron microscopy (SEM) images

To analyse the fibre surface structure, scanning electron micrographs (SEM) were obtained of yarn samples fractured in liquid nitrogen and covered with gold to make them conductive, using a LEO 440 scanning electron microscope.

Bursting strength measurements

To compare the tensile properties of the fibres, the bursting strength of the knitted fabrics were evaluated. The bursting strength was determined according to test method TS 393 EN ISO 13938-1 on a Truburst bursting strength tester (James Heal, England) [19]. For each fibre type, five tests were realised and arithmetic means calculated.

Pilling behaviour

Pilling is a very serious problem for fabrics that arises after their usage. The pilling behaviour of all the fabrics was tested on a Nu-Martindale Abrasion Tester (James Heal, England) according to test method TS EN ISO 12945-2 [20]. According to the pilling test, the fabric is mounted both in the holder and on the base plate so that it is rubbed against itself. After a certain cycle (7000 cycles), the fabric from the holder is usually assessed and given a scale according to a standard fabric photograph. The scales start from grade 5 (no pilling) to grade 1 (severe pilling).

Flame resistance measurements

The samples were placed onto a Govmark TC 45-X 45° (Govmark, United States) flammability tester and a flame was applied to the fabrics at different times, such as 1, 2, 3 etc. seconds. At the end of the test, it was observed whether the sample was burned or not. Moreover the burning time was recorded. All the samples were tested at the same conditions and five samples burned for each fibre type.

Washing process

In the work, we also studied the effect of the washing process on the durability of the flame resistance of the fibres. Fabric samples, particularly soybean, bamboo, cotton and soybean-cotton knitted fabrics were washed 10 times in a Wascator CLS washing machine (SDL Atlas) at 40 °C with ECE detergent without optical brighteners (SDL Atlas). During washing, the dimensions of the knitted samples were 20 × 200 cm (width × length). And then the samples were dried. Five samples were used for the analysis.

Resistance of UV light

Sunlight is the source of all life on earth. Its spectrum extends from 290 nm to 3000 nm at sea level. Small doses of ultraviolet (UV) solar radiation are beneficial to humans, but too much exposure to UV radiation can result in skin damage such as sunburn, allergies and even skin cancer. Recognising these facts, it is clearly very important to protect skin from excessive amounts of UV radiation. This can be done by using sunscreen lotions, hats and sunglasses or by wearing protective clothing. In this study, the resistance to UV light of the fibres analysed was investigated to protect the wearer during usage of the fibres in daily life. The measurements were done on an SDL Atlas tester and five samples were tested for each fibre type.

Air permeability measurements

Air permeability is the rate of air flow passing from the fabric and has an influence on fabric comfort when considering thermal properties of the fabric and interaction between the user body's and clothes. The air permeability of the samples was measured on a Textest FX 3300 tester (Switzerland) according to TS 391 EN ISO 9237 [21]. An average of ten readings for each sample was reported.

Water absorption

In order to keep the wearer dry and hence comfortable, clothing should have the ability to absorb liquid sweat in contact with the skin. In this study, we used the static immersion method to evaluate the water absorption amount according to BS 3449 [22] and calculated it in terms of the following ***Equation 1***. Six specimens were tested for each fibre type. The mean percentage of water absorption is calculated according to the ratio of the weight of water absorbed to the dry fabric weight.

$$Water\ absorption = Awm/Dm \times 100\% \quad (1)$$

were, Awm - absorbed water mass in g, Dm - dry mass in g.

Water vapour permeability

Water vapour permeability is the rate of water vapour transmission through a material and the ability of clothing to transport the water vapour is an important feature regarding physiological comfort. This property was measured by an SDL Atlas water vapour permeability tester. Five measurements were done for each fibre type.

Fabric drape measurements

Drape is the ability of a fabric to fall under its own weight into wavy folds of different nature, comprising the combined effect of several factors such as stiffness, flexural rigidity, weight, thickness etc. Therefore fabric drape is one of the most important properties of fabric and has played a significant role in providing aesthetic effects to a garment. The drapability of the samples was determined according to TS 9693 on a Cusick drape tester (James Heal, England) [23] as well as the drape coefficient for each fibre type, which is the area covered by the shadow of the draped specimen, expressed as a percentage of the area of the annular ring of fabric *e*. Three measurements were done for each fibre type.

Dyeing properties

The knitted fabrics were dyed with the Novacron dye type (vinyl sulfone based) in light, medium and dark colours to compare the dyeing properties of different fibres. Soybean fibres have a light yellow colour and can be dyed with acidic or reactive dyes. However, it was stated that the colour range is narrow and pastel colour tones can be obtained [5]. As mentioned, soybean fibres are protein fibres. In dyeing, opposite to general usage, reactive dye was used to obtain the dark colours. Dyeing was realised based on the padding method on an Ataç Lab-Dye HT 10 sample dyeing machine (Turkey). The dye bath contained 40 g/l salt and 0.3 g/l dyestuff for light colours, 60 g/l salt and 3 g/l dyestuff for medium colours, and 80 g/l salt and 20 g/l dyestuff for darker colours. In the study, soybean and bamboo fabrics were also dyed with acidic dye. The samples were dyed in only medium colours and the dye bath contained 60 g/l salt and 3 g/l dyestuff. pH was adjusted to 11 for reactive dyes while it was 4.5 for acidic dye, and the pick-up was 80% in all the experiments. All knitted samples were rinsed with cold water and dried at 80 °C for 3 minutes. Colour measurements of the dyed samples were performed on a PressCheck portable spectrophotometer Switzerland). Four colour measurements were done for each sample. The CIELAB coordinates (L*, a*, b*) and colour difference (ΔE*) values were measured as colour values. ΔE* was obtained according to the CIEL*a*b* (1976) equation. Wash, rubbing and light fastness measurements were also realised in accordance with the standards of AATCC 61-1993: 1A, TS EN ISO 105-X12 and TS 1008 EN ISO 105 B02 on (James Heal, England), Crockmaster (James Heal, England) and SDL Atlas Xenotest alpha testers, respectively [24 - 26]. In washing fastness measurements, ECE detergent without optical brighteners was used. The washing procedure was realised at 40 °C for 45 minutes with ten steel balls. For washing and rubbing measurements, staining and changes in shade were assessed with the gray scale. For light fastness measurements, the changes in colour were evaluated with the blue scale. Before the measurements, the fabrics were conditioned for 24 hours in a standard atmosphere of temperature 20 ± 2 ºC and relative humidity 65 ± 2%. All

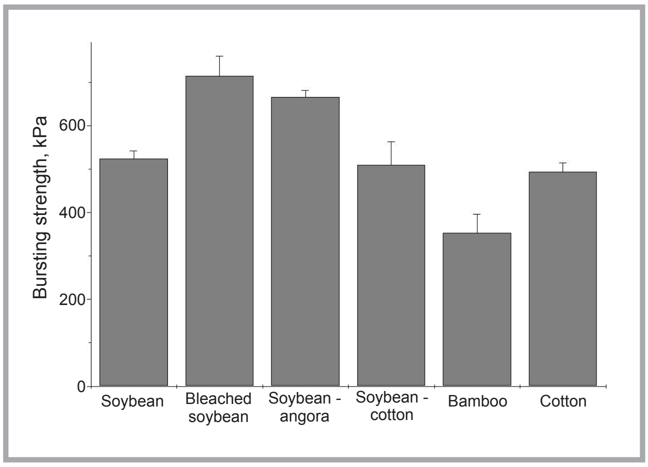

Figure 1. *Bursting strength results of different fibres.*

statistical analyses were made using the SPSS statistic program. Analysis of variance (ANOVA) was applied to the values studied. The results were assessed at a 0.05 level of significance.

Results and discussion

Performance properties

Bursting strength

Bursting strength results of the fabrics are given in ***Figure 1***.

According to ***Figure 1***, the fabric knitted from bleached soybean fibres has the highest bursting strength results while the fabric obtained from bamboo fibres has the lowest. Soybean and its mixtures with angora and cotton fibres also give a higher bursting strength. In literature, it was also stated that soybean fibres are as strong as cotton and other fibres [4, 12, 14, 27]. Soybean fibre tenacity was reported as 3.8 - 4.0 cN/dtex for a dry state and 2.5 - 3.0 cN/dtex for a wet state. As for cotton, the fibres have 1.9 - 3.1 cN/dtex strength values for a dry state and 2.2 - 3.1 cN/dtex for a wet state [4, 27]. Tensile properties of the fibres could be explained with the internal structure of the fibres. Reddy and Yang (2009) calculated the orientation of microfibrils in the fibre to the fibre axis in terms of the microfibrillar angle (MFA). The MFA of the fibres indicates the arrangement of microfibrils along the fibre axis. A lower MFA means a strong but stiff fibre with low elongation [14, 28]. They determined that the MFA of soybean fibres of (10 - 14º) is lower than that for cotton (20 - 30º) but similar to that of the common bast fibres such as linen (8 - 12º) [14, 29]. Good orientation of microfibrils along the fibre axis may lead to higher fibre strength and bursting strength values for soybean fibres. As for bamboo fibre, in addition to the degree of crystallinity, the degree of polymerisation (DP) of bamboo fibre is lower than those of cotton, ramie and flax [30]. Lower DP and fibre orientation may lead to lower tenacity for bamboo fibres. Additionally bleaching generally damages all fibres. However, Vynias et al. reported that proper bleaching treatments lead to a decrease in strength losses of soybean fibres due to bleaching and provide higher tensile properties [7]. On the other hand, differences in the values of bleached soybean and bamboo fibres were found to be statistically significant (***Table 1***). However, there are not statistically significant differences between soybean, soybean-cotton and cotton fibres, and therefore these fibres provide similar bursting strength. Additionally bamboo fibres have significantly lower bursting strength values than the other fibres when the strength properties of soybean fibre and its blends are significantly higher.

Table 1. *ANOVA test results. * - The mean difference is significant at the 0.05 level.*

Fibre type		Significant		
		Bursting strength	Air permeability	Water absorption
Soybean	Bleached soybean	0.000*	0.046*	0.948
	Soybean-angora	0.000*	0.000*	0.262
	Soybean-cotton	0.562	0.000*	0.878
	Bamboo	0.000*	0.000*	0.066
	Cotton	0.202	0.000*	0.014*
Bleached soybean	Soybean-angora	0.046*	0.000*	0.236
	Soybean-cotton	0.000*	0.000*	0.930
	Bamboo	0.000*	0.000*	0.057
	Cotton	0.000*	0.000*	0.012*
Soybean-angora	Soybean-cotton	0.000*	0.000*	0.204
	Bamboo	0.000*	0.000*	0.451
	Cotton	0.000*	0.033*	0.160
Soybean-cotton	Bamboo	0.000*	0.000*	0.047
	Cotton	0.476*	0.000*	0.010*
Bamboo	Cotton	0.000*	0.005*	0.505

Table 2. *Pilling resistance results.*

Fibre types	Cycles						
	125	500	1125	2000	5000	6000	7000
Soybean	4 - 5	4 - 5	4 - 5	4	4	3 - 4	3 - 4
Soybean-cotton	4 - 5	4 - 5	4	3 - 4	3	3	2 - 3
Bamboo	4 - 5	3 - 4	3	2 - 3	2	2	2
Cotton	4	4	4	3 - 4	2 - 3	2 - 3	2

Table 3. *Comparison of flame resistance of the knitted fabrics.*

Fibre type	Flame application time, s	Start time of burning, s	Burning time of the sample, s
Soybean	1, 2, 3, 4, 5	6	27.0
Soybean-cotton	1, 2, 3, 4	5	23.5
Bamboo	1, 2	2	18.05
Cotton	1, 2	2	30.9

Pilling resistance

Table 2 displays differences in the pilling rates of the knitted fabrics produced from different fibres.

The fabrics knitted from soybean fibres has more pill-resistance than the other fabrics obtained from bamboo and cotton fibres. In addition, the soybean-cotton blend also displays better resistance. Therefore soybean fibre and its blends provide adequate resistance to pilling. This result was also obtained by Örtlek and Korkmaz [13]. Higher pill-resistance obtained for soybean fibres can be attributed to the fibre surface. In present study, scanning electron microscope (SEM) views of soybean fibres were taken. As seen in ***Figures 2 - 3*** (see page 18), soybean fibres have a more uneven and grooved structure than bamboo and cotton fibres. In literature, irregular grooves, wrinkles and a kidney bean-like cross-sectional shape were also observed on soybean fibres [12, 15, 16, 27]. In addition, the low friction coefficient of soybean fibre may be another reason for its better pilling resistance [6]. Thanks to the fibre surface structure, soybean fibre and its mixtures featured higher pill-resistance than the other fibres.

On the other hand, in this work, SEM images of bamboo and cotton fibres were also analysed (***Figure 3,*** see page 18). The images of the three fibres show the differences. As is seen, bamboo fibres have a very smooth fibre surface compared to soybean fibres. Similar to previous observations, there was no node in the longitudinal surface of the bamboo fibre [30]. Even the structure of the fibre may unfortunately lead to low resistance

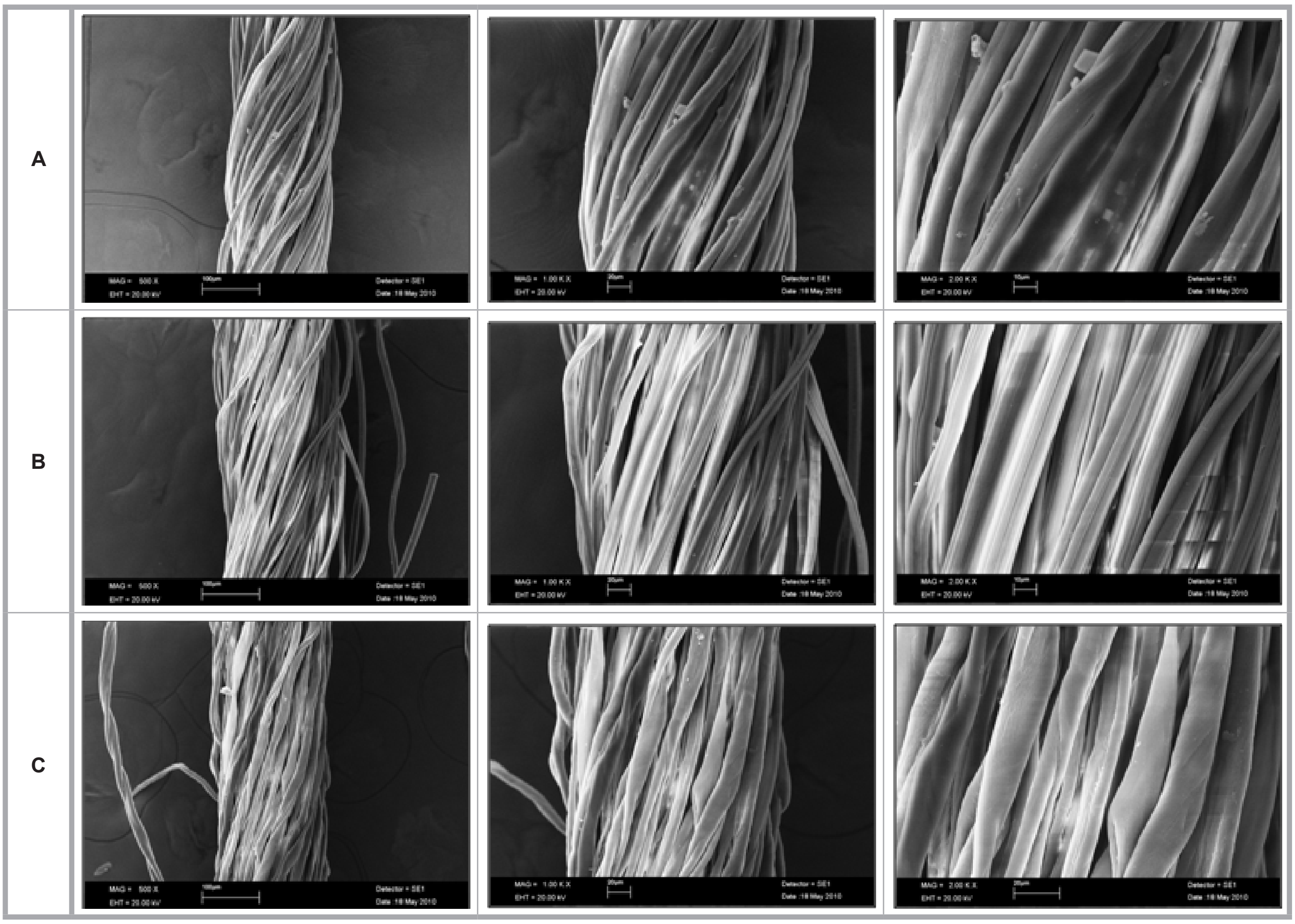

Figure 2. SEM pictures of soybean (A), bamboo (B) and cotton (C) yarns.

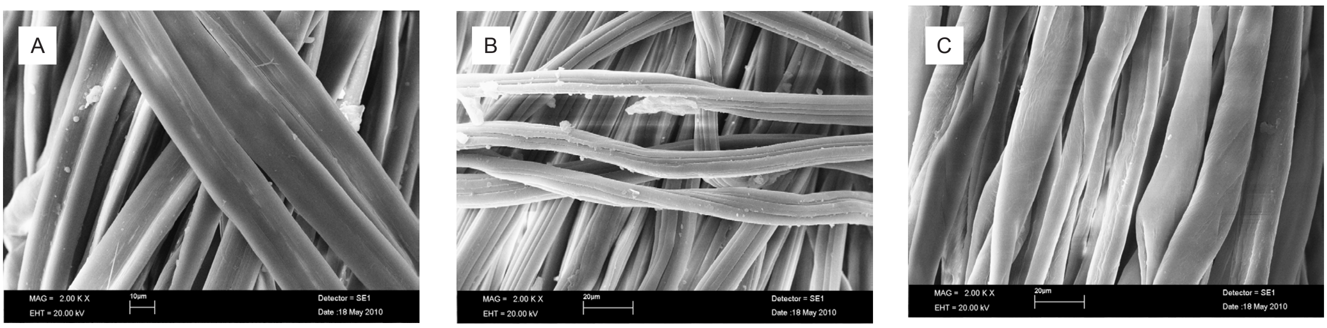

Figure 3. SEM pictures of soybean (A), bamboo (B) and cotton (C) fibres.

to pilling. Bamboo fibres display a tubular and ribbed (celery-like) longitudinal surface, as reported by Waite [32]. Slits on the fibre surface appear prominently. As for cotton fibres, they have helices along the fibre length.

Functional properties

Flame resistance

Fabric samples knitted from different fibres were placed on a 45° flammability tester and a flame was applied to the fabrics at different times. The burning time of the samples was recorded, results of which are given in ***Table 3*** (see page 17). As seen in ***Table 3***, the fabric knitted from soybean fibres requires more flame application time (6 seconds) to start the burning than that of the other fibres (2 seconds). When the flame was applied for one and two seconds, cotton and bamboo fabrics ignited. However, in most cases, no ignition was observed on soybean and soybean-cotton blend fabrics. On the other hand, in soybean and its blends, when the ignition starts, it also requires more time to burn the entire sample. In particular, the total burning time of the soybean samples is higher than that of the bamboo fibre samples. Therefore soybean fibres have more resistance to flame than the other fibres.

In this study, knitted fabrics were washed 10 times and then a flame was applied to them, the results of which are given in ***Table 4***. After washing, in all samples there is a reduction in the times required to start the ignition and to finish the burning. Nevertheless soybean fabrics are still more resistant to flames and burning than bamboo and cotton fibres. This result is similar to that before washing.

Table 4. Test results for washed knitted fabrics.

Fibre type	Flame application time, s	Start time of burning, s	Burning time of the sample, s
Soybean	1, 2, 3, 4	5	24.09
Soybean-cotton	1, 2, 3	4	20.83
Bamboo	1, 2	2	15.85
Cotton	1, 2	2	15.10

Of all the natural textile fibres commonly used, wool, which is one of the protein fibres, is the most resistant to flames i.e. it is difficult to ignite, with any flame spreading slowly and is easily extinguished. Soybean fibre is similar to wool fibre concerning the flame resistance property. The flame resistance property of soybean fibres may result from the fibre's chemical structure. Nitrogen (4.70%) and the high moisture content in its composition may provide soybean fibres with the flame retardant property [32]. In this work, the chemical composition of soybean fibres was analysed, the results of which are given in ***Table 5***. As is seen, soybean fibres basically consist of carbon, oxygen and nitrogen elements. On the other hand, Reddy and Yang (2009) reported that the moisture regain of soybean straw fibres is higher than that of cotton and close to that of linen (14%). As a result, it is believed that the higher flame resistance of soybean fibre results from the nitrogen element in the fibre composition and high moisture content of the fibre. On the other hand, Vynias (2006) reported that soybean fabric has a low LOI value and relatively poor flammability properties in comparison to other proteinaceous fibres such as wool, which typically has an LOI value of 25 - 26%. The reason may be the lower amino acid content (23 - 55%) in soybean fibres in comparison to wool fibres [16]. Soybean fibre contains as many as 18 - 20 amino acids similar to those found in wool and silk, but the proportions are different [33]. Additionally washing leads to a reduction in the flame resistance of soybean fibres, the reason for which may be the low durability of soybean fibre to laundering. Vynias (2010) worked on the modification of the flame-retardant property of soybean fibres with a flame-retardant reagent and reported that the LOI values of fabrics treated were significantly reduced to the same value as that of untreated fabric after three washing cycles. Similar to our results, he observed low protection against the flame after washing. Another reason may be the effect of laundering on the phosphorus and nitrogen content. As determined in literature [11], washing after one and three cycles may reduce the N/P ratio on the fibre surface.

Ultraviolet protection

The ultraviolet protection factor (UPF) is used to indicate the amount of UV protection provided to skin by fabric. UPF is defined as the ratio of the average effective UV irradiance calculated for unprotected skin to the average UV irradiance calculated for skin protected by the test fabric. The higher a value, the longer a person can stay in the sun until the area of skin under the fabric becomes red [34 - 36]. Mean ultraviolet protection factor values of fabrics knitted from different fibres are given in ***Table 6***.

Table 5. EDAX results of soybean fibres.

Element	Weight (%)
C	65.87
O	27.69
N	4.70
Ca	1.18
P	0.33
S	0.23

UPF values of the fibres showed that the fabrics obtained from cotton and then bamboo fibres afforded poor protection against ultraviolet radiation. However, the soybean-angora blend followed by soybean fibres provide the highest protection. On the other hand, soybean fibres have more resistance to ultraviolet radiation and hence give higher UPF values. Interestingly the blending of soybean fibres with cotton decreases the resistance to ultraviolet radiation considerably due to the inadequate UV protection of cotton fibres. As expected, the blending of soybean fibres with angora fibre increases the UV protection. In addition to soybean fibre properties, the bulky structure of angora yarns could be another reason for the high UV resistance of soybean-angora fabrics. The UV barrier properties of a textile is strongly related to its structure, mainly fabric density and yarn hairiness. Fabrics made of angora are very fluffy due to the high hairiness of yarn. The free ends of angora fibers fill loops - spaces between yarns in the fabric, and block access of UV rays to the skin.

Fabrics with a UPF value in the range 15 - 24 are classified as having "Good UV Protection"; when the UPF values are between 25 and 39 fabrics are classified as having "Very Good UV Protection", and the "Excellent UV Protection" classification is used when the UPF is 40 or greater [25]. According to this classification, the soybean-angora blend can be called a very good UV protector. Although its UPF value is lower than 15, soybean fibre can be accepted as a good UV protector due its higher UPF value compared to that of the other fibres. Rijavec and Zupin (2012) and Orion Filati S.r.l. Stated the UV resistance property of soybean fibres [16, 27]. However, in literature, there are not any findings or values about the UV resistance property of soybean fibres. Ultraviolet absorbance by the fibre structure may be an explanation for the high resistance to ultraviolet radiation of soybean fibre.

Comfort properties

Air permeability

Air permeability values of the fabrics are given in ***Figure 4*** (see page 20).

As seen in ***Figure 4***, the highest air permeability value was obtained for bamboo fabric, which was followed by cotton and soybean-cotton fabrics, in turn. On the other hand, bleached soybean and soybean-angora blend fibres give the lowest air permeability values. According to the statistical analysis of experimental data, there is a statistically significant difference in the values of all fibres, from which we can conclude that bamboo significantly allows the most air passage

Table 6. UV protective property for different fibres.

Fibre type	Mean UVA (315-400 nm), %	Mean UVB (290-315 nm), %	Mean UPF
Soybean	10.2	6.8	13.70
Soybean-angora	5.0	3.7	29.80
Soybean-cotton	18.0	14.6	06.72
Bamboo	29.6	22.2	04.38
Cotton	31.3	24.8	03.89

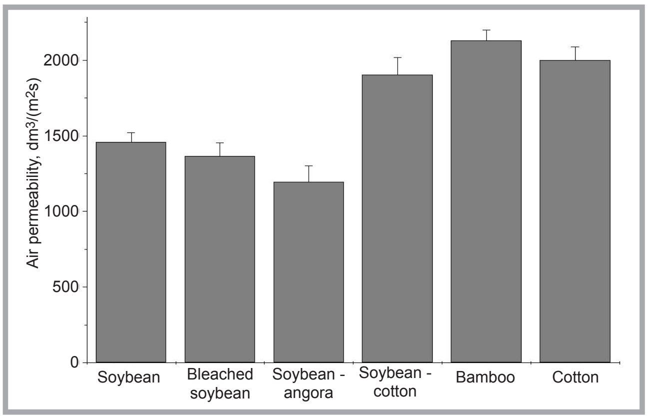

Figure 4. *Air permeability results of the fabrics.*

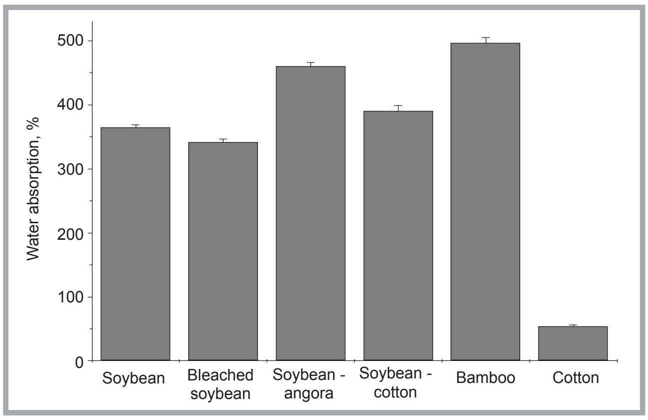

Figure 5. *Water absorption results of the fabrics.*

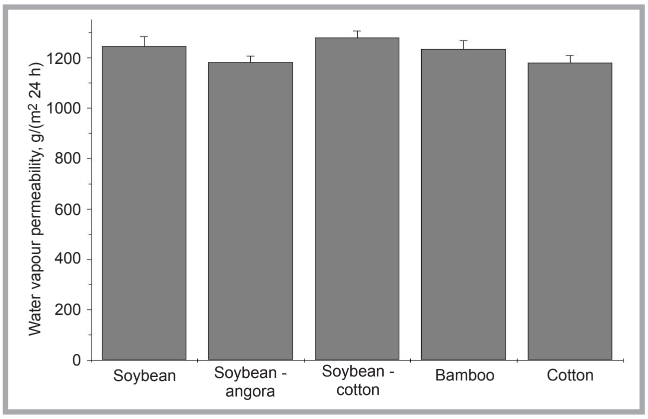

Figure 6. *Water vapour permeability results of the fabrics.*

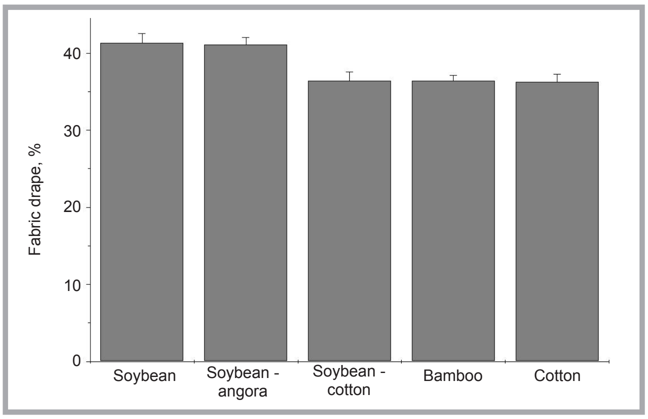

Figure 7. *Fabric drape results of the fabrics.*

while soybean-angora blend fabric provides the lowest (***Table 1***).

Lower air permeability values of soybean and its blends were found by Marmaralı et al. (2009). In particular, the higher air permeability results of cotton and soybean-cotton blend fabrics coincide with the finding of this work. Air permeability is a property also related to fabric thickness and surface characteristics of fibres [8]. Although the density and, hence, thickness values of the fabrics are almost the same, the air permeability of the bamboo fabric was higher than that of the soybean and cotton samples, which may be partly attributed to the fact that soybean fibres have a more grooved structure than bamboo and cotton fibres [12]. This might increase friction between the fibre surface and air, resulting in a decrease in the air permeability of samples from these fibres. Soybean fibre has been mentioned to have as smooth and light a handle as that of cashmere [5], the characteristic of which may lead to low spinnability and an increase in yarn hairiness. Higher yarn hairiness may be another reason for the lower air passage of soybean fabrics. The relationship between yarn hairiness and air permeability was reported in literature [38 - 40]; the hairiness or amount of hair protruding from the yarn surface influences the openness of the fabric structure and hence air permeability. When the results of soybean-angora blended fabrics were analysed, it was seen that air permeability values are worse than those of soybean fibres. Angora fibre is known for its smooth and lustrous surface. In literature, it was determined that yarn containing Angora rabbit fibre causes fabric hairiness and thus lower air passage [38]. As for soybean-cotton blended fabrics, the opposite is the case, and their air permeability values are statistically better than soybean and soybean-angora blended fabrics. Angora blending increases fibre slippage during spinning. However, in cotton blending, soybean and cotton fibres may hold together, and slipping may decrease. This case may provide less hairy yarn and higher air passage. On the other hand, as mentioned above, bamboo fibres have a smoother structure, and this may improve the air permeability property of bamboo fabric.

Water absorption

The results are presented in ***Figure 5.***

As seen in ***Figure 5***, bamboo and soybean-angora blend fabrics have the highest water absorption amount while cotton fabric has the lowest. Particularly there is only a statistically significant difference in the water absorption values of cotton and other fibres, and hence cotton fabric absorbs statistically the lowest water (***Table 1***). Other fabrics absorb a statistically similar amount of water. The lower water absorption of cotton may result from substances such as oil and wax in the cotton fibre. On the other hand, the better water absorption property of bamboo and soybean fibres was stated in literature, which may result from their structures; particularly micro-holes in the cross-section of fibres may improve the water absorption capacity. When a fabric is immersed in a liquid, water enters the space between fibres in the yarns and between yarns in the fabric [6, 8, 41]. Another reason for water absorption may be the internal structure of fibres. The crystallinity degree was determined 64.43 % for cotton, 52.54 % for bamboo fibre [30] and 47 % for soybean fibre [14]. Lower crystallinity means higher amorphous regions, resulting in higher accessibility to water for soybean and bamboo fibres. In addition to higher crystallinity, the porous structure of bamboo fibres may also be responsible for their high water absorption capacity. Micro-pores and spaces in the bamboo fibre cross-section make a considerable contribution to attaining the highest water absorption. Therefore moisture regain is reported to be about 13% for bamboo, 9 - 11% for soybean and 7.5 - 8% for cotton fibre [3, 6, 8, 42]. On the other hand, angora fibre also has a higher moisture regain of 17 - 18.25% [43, 44]. Angora fibre may improve the water absorption of soybean-angora blended fabric.

Water vapour permeability

Figure 6 illustrates the water vapour permeability results of fabrics knitted from different fibres.

Figure 6 shows that the water vapour permeability of the soybean-cotton fabric was the highest, while soybean-angora and cotton fabrics give the lowest values. This result show similarity to those for air permeability . In addition, the higher water vapour permeability results of soybean and bamboo fabrics coincides with the findings of Cimili et al. (2010), and Marmaralı et al. (2009) also determined that soybean-cotton fabric gives higher values than those of cotton fabric. In the literature, it was reported that water vapour transfer was mainly affected by two factors: the air permeability and regain of fabrics [8]. Fibres such as soybean-cotton, with soybean fibres having higher air permeability values, give higher water vapour permeability values, and that finding is in agreement with this statement. On the other hand, the lowest water vapour permeability value of soybean-angora blend fibre may mainly result from it having the lowest air permeability and also higher water absorption values. In spite of its considerably higher air permeability values, bamboo fibre allows lower water vapour permeability due to its higher water absorption value. On the other hand, soybean-cotton fibre has higher air permeability and medium water absorption values, which may lead to higher water vapour permeability.

Fabric drape

Figure 7 shows the fabric drape results of knitted fabrics obtained from different fibres.

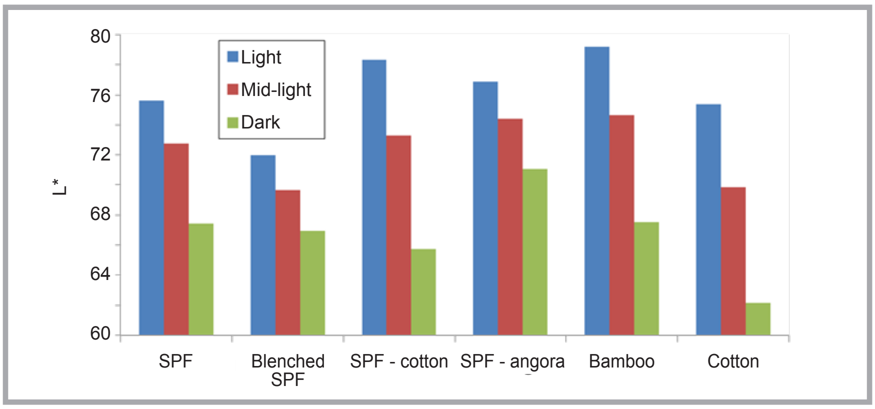

Figure 8. *L* values of the knitted fabrics.*

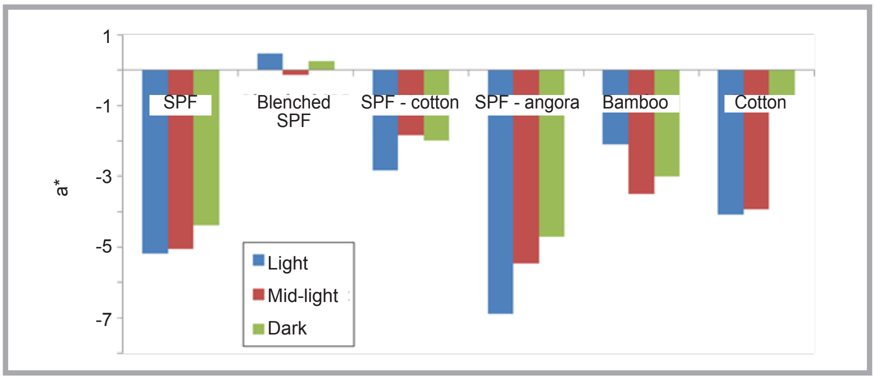

Figure 9. *a* values of the fabrics.*

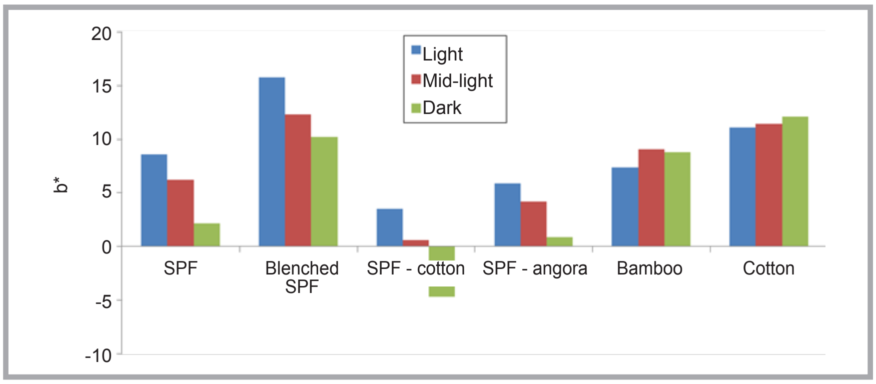

Figure 10. *b* values of the fabrics.*

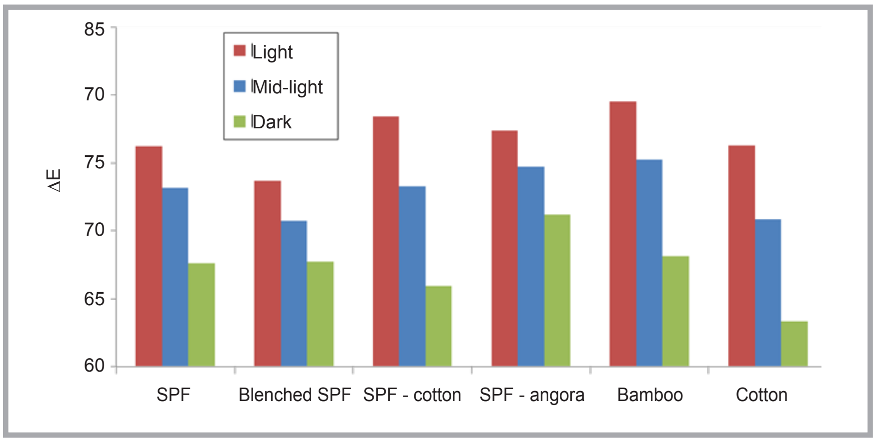

Figure 11. *ΔE values of the fabrics.*

Table 7. All colour values for different dyes.

Type of dyes	Fibres	L*	a*	b*
Navacron reactive	Soybean	72.76	-5.04	6.19
	Bamboo	74.65	-3.49	9.06
Acidic	Soybean	60.22	4.97	-2.51
	Bamboo	80.61	0.19	1.22

Table 8. Washing fastness results of all dyed fabrics for staining.

Dying	Fibre types	Multifibre						General result
		Acetate	Bleached cotton	Nylon	Polyester	Acrylic	Wool	
Light	SPF	5	4/5-5	5	5	5	5	4/5-5
	Bleached SPF	5	5	5	5	5	5	5
	SPF-cotton	5	5	5	5	5	5	5
	SPF-angora	5	5	5	5	5	5	5
	Bamboo	5	5	4/5	5	5	5	4/5
	Cotton	5	5	5	5	5	5	5
Mid-light	SPF	5	5	5	5	5	5	5
	Bleached SPF	5	5	5	5	5	5	5
	SPF-cotton	5	5	5	5	5	5	5
	SPF-angora	5	5	5	5	5	5	5
	Bamboo	5	5	4/5	5	5	5	4/5
	Cotton	5	5	4/5	5	5	5	4/5
Dark	SPF	5	5	5	5	5	5	5
	Bleached SPF	5	5	5	5	5	5	5
	SPF-cotton	5	5	5	5	5	5	5
	SPF-angora	5	5	4/5-5	5	5	5	4/5-5
	Bamboo	5	5	4/5	5	5	5	4/5
	Cotton	5	5	4	5	5	5	4

The drapability of the samples is given by the drape coefficient, being the area covered by the shadow of the draped specimen to the area of the annular ring of fabric. The criterion of the drape coefficient was that it could give an integrated measure, similar to that of a human being [45]. As seen in ***Figure 7***, soybean and soybean-angora blend fabrics have higher fabric drape values, and hence fabrics knitted from these fibres could provide more drapability. In literature, the soft and smooth handle of soybean protein fibre was stated, and hence it can be concluded that the fibre is very comfortable to wear [1, 4, 6, 41]. Fabric drape coefficients determined in this study prove the comfort characteristics of soybean fibre. The higher drape coefficient of soybean fibre may result from its low cohesion force and friction coefficient . The crimp ratio was determined as 1.65% for soybean fibre, while the value reported for other chemical fibres was 10 - 15%. This means that when soybean fibre is crimped or folded, it is easy to unwind [6]. On the other hand, fabric drape values of the fabrics decrease as the soybean fibre blends with other fibres. Particularly cotton and cotton blends give lower fabric drape values because cotton is a rigid fibre.

Dyeing Characteristics

The L*, a*, b* and ΔE results of all the plain knitted fabrics are presented in ***Figures 8 - 11***. The L* value represents lightness and varies from 0 (black) to 100 (white). a* and b* values refer to redness-greenness and yellowness-blueness, respectively.

L* values presented in ***Figure 8*** reveal that L* values decrease as the fabrics are dyed from lighter to darker. As is known, the colour gets darker as the L* values decrease. When the L* values of the different fibres were compared, it was determined that bamboo and soybean-angora blend fibres have higher values for light, medium and darker colours than those of the other fibres. On the other hand, lower L* values were obtained with bleached soybean and cotton fibres. Therefore bamboo and soybean-angora blend fibres give lighter colour tones while bleached soybean and cotton fibres provide darker colours.

From ***Figures 9 - 10*** it can be seen that most of the a* values (redness) are lower than those of b* (blueness), which means that the colours of all the fabrics are bluer rather than redder. Most of the fabrics are closer to blue than red. Bleached soybean fibre has higher a* and b* values than those of the other fibres. Regarding a* values, soybean and soybean-angora fibres have lower ones, and hence other fibres are redder than soybean and soybean-angora blend fibres. As for b* results, soybean-cotton blend fabric seems greener than the other fibres due to its lower b* values.

ΔE values reveal the colour differences of the fabrics, and the results indicate that bamboo fibre has the highest values, while bleached soybean and cotton fibres have the lowest. Therefore colour differences between bamboo and bleached soybean/cotton are the highest. On the other hand, soybean, soybean-angora and cotton fibres have a similar colour.

In the study, soybean and bamboo fabrics were also dyed with acidic dye and the colour values compared with Novacron reactive dye (***Table 7***). As seen in Table 7, soybean fibre has lower L* values than bamboo fibre for both dye types, therefore soybean fibre gives darker colour tones than bamboo fibre.

The differences in L* colour values of the fibres may arise from the variations in their molecular structure. The diffusion of dye molecules into fibres mainly depends on the size and distribution of the crystalline (ordered) and amorphous (disordered) regions. Lower crystallinity and, hence, higher amorphous regions cause more dye molecules to diffuse into the fibre [46]. As is mentioned, the crystallinity degree of soybean fibre is lower than that of cotton and bamboo fibres. Therefore it would be easier for dye molecules to diffuse into soybean fibre than into bamboo and cotton fibres, which leads to lower L* values for soybean fabrics. On the other hand, the whitening effect was only marginally further improved by the bleaching treatment, with improved colour [7]. Bleaching also removes soils and other contaminants from the fibre surface, as a consequence of which the fibre can absorb more dye stuff from the dye liqour, providing a darker but less yellowish colour tone.

Table 9. Washing fastness results of all dyed fabrics for shade change.

Fibre type	Light	Mid-light	Dark
SPF	5	5	5
Bleached SPF	5	5	5
SPF-cotton	5	5	5
SPF-angora	5	5	5
Bamboo	5	5	5
Cotton	5	5	5

Table 10. Dry and wet rubbing fastness results of all the dyed fabrics.

Dying	Fibre type	Dry	Wet
Light	SPF	5	5
	Bleached SPF	5	5
	SPF-cotton	5	5
	SPF-angora	5	5
	Bamboo	5	5
	Cotton	5	5
Mid-light	SPF	5	5
	Bleached SPF	5	5
	SPF-cotton	5	5
	SPF-angora	5	5
	Bamboo	5	5
	Cotton	5	5
Dark	SPF	5	5
	Bleached SPF	5	5
	SPF-cotton	5	5
	SPF-angora	5	5
	Bamboo	5	5
	Cotton	5	5

Table 11. Light fastness results of all the dyed fabrics.

Dying	Fibre type	Values
Light	SPF	3/4
	Bleached SPF	4
	SPF-cotton	3
	SPF-angora	4
	Bamboo	4
	Cotton	3/4
Mid-light	SPF	4
	Bleached SPF	4
	SPF-cotton	3
	SPF-angora	4
	Bamboo	3/4
	Cotton	3
Dark	SPF	4
	Bleached SPF	4
	SPF-cotton	3
	SPF-angora	3/4
	Bamboo	3/4
	Cotton	3

Reactive dyes are the best of all for cotton and other cellulose fibres. They are also used for protein fibre dying. Our study is proof that reactive dye can dye bamboo and soybean fibres. On the other hand, bamboo fibre contains mostly cellulose. However, soybean fibres have a high content of protein. It is easier to dye protein fibre than cellulose fibres with reactive dye, and soybean fibre gives a little bit darker colour tone than bamboo. Acid dyes can dye only protein fibres, hence with acid dye, soybean gives a darker colour.

Colour fastness

In present study, colour fastness to washing, rubbing and light were studied, the results of which are given in ***Tables 8 - 11*** for all fibre types.

As seen in ***Table 8***, all fabrics knitted from different fibre types have excellent colour fastness values. However, comparing to other fibres, particularly bamboo fibre, cotton fibres give lower colour fastness values for the three colour types. Therefore bamboo and cotton fibres are more sensitive to staining than the other fibres, and hence they reveal slightly worse washing fastness results than the other fibre types. On the other hand, all the results for washing fastness for shade change and wet and dry rubbing fastness are 5 (***Tables 9 - 10***). Regarding soybean fibre and its blends, good colour fastness values were reported [6, 27].

Finally the light fastness results are given in ***Table 11***. In general, comparing to the washing and rubbing fastness results, those for light fastness of all the fabrics are not very good, with the ratings being below 5. However, the highest light fastness values were observed for bleached soybean, followed by soybean and soybean-angora blend fibres. On the other hand, cotton and soybean-cotton blend fibres reveal the lowest fastness results. The higher light fastness values of soybean and soybean-angora blend fibres may result from their UV resistance property [46].

On the other hand, bleached soybean fibre and soybean fibre blends give good colour fastness values with darker colour tones and are stable against effects such as washing, rubbing and sunshine. However, bamboo fibre could be dyed into lighter colour tones, with the colour resistance to washing and light found to be lower. On the other hand, silk fibre attracts our attention with its smooth drape and lustrous appearance. The main problem of silk fibre is stability of dying. Soybean fibre may meet colour fastness requirements as well as drape while maintaining its appearance.

Conclusions

Soybean fibre is one of the new generated fibres. In the study, the characteristics of soybean protein fibre and its blends were compared with those of bamboo and cotton fibres since they are usually used in textile products. When the performance properties of soybean fibre were analysed, it was found that fabrics knitted from soybean and its mixtures with various fibres give higher bursting strength and better pill-resistance than bamboo and cotton fabrics. The smooth and lustrous surface characteristic of soybean fibre causes hairy yarn production with lower air passage compared to that of bamboo and cotton fabrics. Micro-holes in the cross-section and high amorphous regions of bamboo and soybean fibres improve water the absorption capacity of fabrics. Higher air permeability and lower water absorption mostly lead to an increase in water vapour transfer. Fibres such as soybean-cotton and soybean, having higher air permeability values, give the highest water vapour permeability values, while the lowest water vapour permeability values were obtained from soybean-angora blend fibre due to its lower air permeability and higher water absorption values. As mentioned in literature, soybean and soybean-angora blend fabrics have higher drapability than that of bamboo and cotton fibres. On the other hand, the fabric drape values of soybean fabrics decrease when blended with other fibres; particularly cotton fibre causes a rigid fabric characteristic. In addition to performance and comfort properties, this study researched the functional properties of the fibres. It was shown that soybean fibres have more resistance to flames and UV transmission than bamboo and cotton fibres. In the last section of the study, all fabrics were dyed in light, mid-light and dark colour tones, and the results indicated that bamboo and soybean-angora blend fibres give lighter colour tones, while bleached soybean and cotton fibres provide darker colours. According to a* and b* values, the colours of all the fabrics are bluer rather than redder. The washing and rubbing fastness properties of all fibres are excellent. However, the light fastness results of all the fabrics are not very good, with the ratings being below 5. Nevertheless bleached soybean, followed by soybean and soybean-angora blend fibres reveal the highest light fastness results.

In the event of danger, in order to preserve the spread of fire, flame resistance has vital importance. Additionally, in recent years, skin cancer cases have increased. Therefore soybean fibre attracts extra attention with its functional properties. On the other hand, soybean fibre provides better visual aesthetic properties than silk fibre, as well as a soft, smooth, light and lustrous silky handle. Consequently soybean fibre can meet the performance, comfort and functional demands of classical and technical textile products.

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References

1. Zupin Z, Dimitrovski K. Properties of Fabrics From Cotton and Biodegradable Yarns Bamboo, SPF, PLA in Weft. www.intechopen.com/download/pdf/pdfs, 2011.
2. Anounymous. Soybean Protein Fiber. http://www.apparelsearch.com, 2011.
3. Yi-You L. The Soybean Protein Fibre- A Healthy&Comfortable Fibre For The 21st Century. *Fibres & Textiles in Eastern Europe,* 2004; 12: 8.
4. Özgen B. New Biodegradable Fibres, Yarn Properties and Their Applications in Textiles: a Review. *Industria Textile* 2012; 63: 3-6.
5. Anounymous. Soya Silk - Ecological Textile. www.hayteks.biz.tr, 2011.
6. Anounymous. Properties of Soybean Protein Fibers and Yarns. www.swicofil.com, 2011.
7. Vynias D, Owens H, Carr CM. Surface and Bulk Analysis Of Bleaching Soybean Fabric in The Presence of Protein Hydrolysate. *Journal Applied Polymer Science* 2013; 128: 4271–4276.
8. Cimilli S, Nergis BU, Candan C, Özdemir M. A Comparative Study Of Some Comfort-Related Properties of Socks of Different Fiber Types. *Textile Research Journal* 2010; 80: 948.
9. Ciukas R, Abramaviciüte J, Kerpauskas P. Investigation of the Thermal Properties of Socks Knitted from Yarns with Peculiar Properties. Part I. Thermal Conductivity Coefficient of Socks Knitted from Natural and Synthetic Textured Yarns. *Fibres & Textiles in Eastern Europe* 2010; 18(3): 89-93.
10. Kavuşturan Y, Çeven EK, Özdemir Ö. Effect Of Chenille Yarns Produced With Selected Comfort Fibres On The Abrasion And Bending Properties Of Knitted Fabrics. *Fibres & Textiles in Eastern Europe* 2010; 18: 48.
11. Vynias D. Investigation into the Flame Retardant Properties of Soybean Fabric Treated with Sulphamic Acid. *Journal of Applied Polymer Science* 2010; 117: 875–881.
12. Marmarali A, Blaga M, Üte TB, Damcı G. Thermal Comfort Properties Of Blended Yarns Knitted Fabrics. In: *ITMC 2009 International Conference,* 2009, Morrocco.
13. Örtlek HG, Korkmaz M. Soya Fasülyesi İpliğinin Örme Kumaş Formundaki Performansının İncelenmesi. www.ggctt.com/tr/%3f/ggctt3/26, 2011.
14. Reddy N, Yang Y. Natural Cellulose Fibers From Soybean Straw. *Bioresource Technology* 2009; 100: 3593.
15. Vynias D. Soybean Fibre A Novel Fibre In The Textile Industry. Http://Cdn.Intechopen.Com/Pdfs/15723/Intech-Soybean_Fibre_A_Novel_Fibre_In_The_Textile_Industry.Pdf, 2006
16. Rijavec T, Zupin Z. *Recent Trends for Enhancing the Diversity and Quality of Soybean Products: Soybean Protein Fibres (SPF).* 2012, 501.
17. Kitapçı K, Kılıç H. *Determination Of Performance and Dyeing Properties of Soybean Fibres.* Bachelor Thesis, Suleyman Demirel University, Engineering Faculty, Textile Engineering Department, Isparta, Turkey, 2012.
18. Yelkovan S. *Investigation Of Functional Properties of the Fabrics Obtained from Soybean Fibres.* Bachelor Thesis, Suleyman Demirel University, Engineering Faculty, Textile Engineering Department, Isparta, Turkey, 2010.
19. TS 393 EN ISO 13938-1 Textiles- Bursting Properties of Fabrics- Part 1: Hydraulic Method for Determination of Bursting Strength and Bursting Distension, 2002.
20. TS EN ISO 12945-2 Textiles- Determination of Fabric Propensity to Surface Fuzzing And To Pilling- Part 2: Modified Martindale Method (ISO 12945-2:2000), 2002.
21. TS 391 EN ISO 9237 Textiles-Determination of Permeability of Fabrics to Air, 1999.
22. BS 3449 Testing The Resistance of Fabrics to Water Absorption (Static Immersion Test).
23. TS 9693 Textiles The Assessment of Drape of Fabrics, 1991.
24. AATCC 61-1993: 1A Colorfastness to Laundering, Home and Commercial: Accelerated (Hand Wash), 1993.
25. TS EN ISO 105-X12 Textiles - Tests for Colour Fastness - Part X12: Colour Fastness To Rubbing, 2006.
26. TS 1008 EN ISO 105 B02 Textiles- Tests For Colour Fastness- Part B02: Colour Fastness to Artificial Light: Xenon Arc Fading Test, 2001.
27. Anonymous, Soybean Protein Fibre: Cashmere Vegetable. http://www.Orionfilati.It, 2011.
29. Morton EW, Hearle JWS. *Physical Properties Of Textile Fibers.* The Textile Institute, Manchester, 1993.
30. Batra SK. *Handbook of Fibre Science And Technology: Other Long Vegetable Fibers.* M. Lewin, And E.M. Pearce Editions, Fibre Chemistry, 4, 1998, Marcel Dekker Inc., New York, p. 505–571.
31. Yueping W, Ge W, Haitao C, Genlin T, Zheng L, Feng XQ, Xiangqi Z. Structures of Bamboo Fiber for Textiles. *Textile Research Journal* 2010; 80: 334-343.
32. Waite M. Sustainable Textiles: The Role Of Bamboo And A Comparison Of Bamboo Textile Properties (II). *Journal Of Textile And Apparel Technology And Management* 2010; 6: 1.
33. Johnson NAG, Wood EJ, Ingham PE, Mcneil SJ, Mcfarlane ID. Wool As A Technical Fiber. *Journal Of Textile Institute* 2003; 94: 26.
34. Rippon JA. *Wool Dyeing*, Bradford: SDC 1992, 19.
35. Hatch KL. Fry Not! UV-Protective Textile Standards. *ASTM Stand News* 2001; 29: 18-21.
36. Crews PC, Kachman S, Beyer AG. Influences On UVR Transmission Of Undyed Woven Fabrics. *Textile Chemist Colorist* 1999; 31: 17-26.
37. Sarkar AK, Appidi S. Single Bath Process For Imparting Antimicrobial Activity And Ultraviolet Protective Property To Bamboo Viscose Fabric. *Cellulose* 2009; 16: 923.
38. Hatch KL. Making A Claim That A Garment Is UV Protective. *AATCC Revision* 2003; 3: 23-26.
39. Oğlakçıoğlu N, Çelik P, Üte TB, Marmaralı A, Kadoğlu H. Thermal Comfort Properties Of Angora Rabbit/Cotton Fiber Blended Knitted Fabrics. *Textile Research Journal* 2009; 79: 888-894.
40. Stankovic S, Popovic D, Poparic GB. Thermal Properties Of Textile Fabrics Made Of Natural And Regenerated Cellulose Fibers. *Polymer Testing* 2008; 27: 41-48.
41. Majumdar A, Mukhopadhyay S, Yadav R. Thermal Properties Of Knitted Fabrics Made From Cotton And Regenerated Bamboo Cellulosic Fibres. *International Journal Of Thermal Sciences* 2010; 49: 2042-2048.
42. Anounymous. Experience the Unparalleled Advantages of Bamboo Yarn and Bamboo Fabric!. www.bambrotex.com, 2012.
43. Xu Y, Lu Z, Tang R. Structure And Thermal Properties Of Bamboo Viscose, Tencel And Conventional Viscose Fiber. *Journal of Thermal Analysis and Calorimetry* 2007; 89: 197-201.
44. Ahlawat SS, Khanna N, Sharma DP, Panda PC. Effect Of Feeding Poultry Viscera Meal On Wool Traits Of Angora Rabbits. *Indian Journal Animal Research* 2003; 37: 130-132.
45. Anounymous, http://www.wira.com, 2013.
46. Li Y. The Science Of Clothing Comfort. *Textile Progress* 2001. The Textile Institute, Manchester, 31(1): 102-103.
47. Gün AD, Tiber B. Color, Color Fastness And Abrasion Properties Of 50/50 Bamboo/Cotton Blended Plain Knitted Fabrics In Three Different Stitch Lengths. *Textile Research Journal* 2011; 81: 1903-1915.

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