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Tekstilije iz novih sojinih proteinskih vlaken (SPF)

Izvirni znanstveni članek

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Izvleček

Nova sojina proteinska vlakna (SPF) so bikonstituentna vlakna, izdelana iz 5–23 % sojinih proteinov in 77–95 % polivinilalkohola. Uporabljeni sojini proteini so stranski proizvod pri pridobivanju sojinega olja. V članku so opisani kemična in nadmolekulska struktura sojinih beljakovin, postopek izdelave SPF-vlaken in njihove lastnosti. Pričakovana biorazgradljivost SPF-vlaken temelji na znani biorazgradljivosti sojinih beljakovin in polivinilalkohola, kakor tudi filmov iz sojinih beljakovin in polivinilalkohola. Preje iz 100-odstotnih SPF--vlaken in tkanine iz bombaža v osnovi in SPF-vlaken v votku so bile 21 dni zakopane v humusni zemlji pri temperaturi 30 °C, 65-odstotni relativni vlažnosti, pri pH 6. Razmere, v katerih nastopi hitra biorazgradnja čistih bombažnih tekstilij, so povzročile minimalno poslabšanje mehanskih lastnosti preje iz SPF-vlaken. Spektri ATR FT–IR kažejo na oslabitev medmolekulskih vodikovih vezi med segmenti protein-protein, PVA–PVA in protein–PVA in posledično povečanje dezorientacije v vrhnjih plasteh SPF-vlaken. Vsebnost SPF-vlaken v tkanini v smeri votka je vplivala na podaljšano ohranitev mehanskih lastnosti in strukture tkanine kot celote.

Ključne besede: fitoproteinska vlakna, sojina proteinska vlakna, polivinilalkohol, razgradnja

Abstract

New soybean protein fibres (SPF) are biconstituent fibres containing 5–23% of soybean proteins and 77–95% of polyvinyl alcohol (PVA). Soybean proteins used for the manufacture of SPF are by-products of the soybean oil production. The chemical and supramolecular structure of soybean proteins, the process of manufacture SPF fibres, and their properties are described in the article. The expected biodegradability of SPF is based on the well-known biodegradability of soybean proteins and polyvinyl alcohol as well on the biodegradability of the films made from soybean proteins and polyvinyl alcohol. Yarns made from 100% SPF and 100% cotton, and fabrics made from 100% cotton fibres and from cotton fibres in warp and SPF in weft were buried for 21 days in humus soil with temperature 30 °C, relative humidity 65% and pH 6. The conditions under which rapid biodegradation of pure cotton textiles took place induced only a slight decrease of mechanical properties of the SPF yarn. ATR FT–IR spectra displayed a reduction of intermolecular hydrogen bonds between protein-protein, PVA–PVA and protein–PVA segments and, consequently, the increase of disorientation in

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the upper layers of soybean protein fibres. The content of SPF in weft direction was responsible for the prolonged retention of mechanical properties and structure of the fabric as a whole.

Keywords: phytoprotein fibres, soybean protein fibres (SPF), polyvinyl alcohol (PVA), degradation

1 Introduction

New soybean protein fibres (SPF) used in experiments are the only commercially produced fibres containing soybean proteins at the moment [1]. They are synthetic composite fibres composed of 77–95% of polyvinyl alcohol (PVA) and 5–23% of soybean proteins, which are in fact the residue after the extraction of oil from the seeds of Glycine Max L soybean. These fibres are primarily designed for garments. Commercially available, beside yarns made from 100% SPF, are also the blends with cotton, viscose, lyocell, silk, cashmere, wool and polyester fibres [1, 2].

Synthetic composite fibres can contain not only soybean proteins but also other kinds of plant proteins, such as proteins extracted from peanuts (ardil proteins) or from the seeds of cotton [3, 4].

The content of proteins in soybean seeds is about 37–42% and is substantially higher than that in milk (3.2%), corn grains (10%) and peanuts (25%) [5]. Soybean proteins are used for food and fodder, and in industry for production of adhesives, emulsions, inks, pharmaceuticals, plastics and even textile fibres. They are becoming more and more important for the production of biodegradable foils where they solve the problem of water absorption and low strength in wet state by cross-linking proteins with palm oil or stearic acid [6] or by adding polyvinyl alcohol [7].

The amino acid composition of soybean proteins (Table 1) resembles the amino acid composition of keratin more than that of fibroin (Figure 1). Soybean proteins contain two amino acids, isoleucine and histidine, which are not present in wool keratin. However, soybean proteins have practically no cystine bonds, which are important intermolecular covalent bonds

1 Uvod

Nova sojina proteinska vlakna (SPF), ki smo jih uporabili v raziskavi, so danes edina tržno dostopna vlakna, ki vsebujejo sojine proteine [1]. To so sintetična kompozitna vlakna iz 77–95 % polivinilalkohola (PVA) in 5–23 % sojinih proteinov, ki izvirajo iz stranskega proizvoda pridobivanja olja iz soje Glycine Max L. Nova vlakna so namenjena predvsem za oblačila. Poleg prej iz 100-odstotno novih sojinih proteinskih vlaken so na trgu mešanice z bombažem, viskoznimi vlakni, liocelnimi vlakni, svilo, kašmirjem, volno in poliestrskimi vlakni [1, 2].

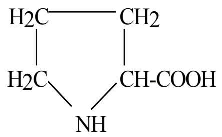
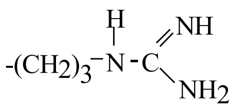
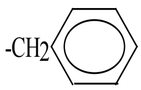
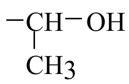
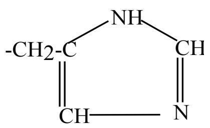
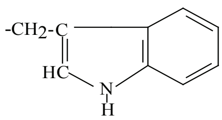
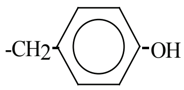
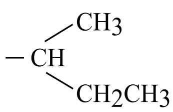
Razen sojinih proteinov lahko sintetična kompozitna vlakna vsebujejo tudi druge vrste rastlinskih proteinov, predvsem iz arašidov (ardilni proteini) ali bombažnih semen [3, 4].

Vsebnost proteinov v sojinih semenih je 37–42-odstotna in je bistveno večja kot v mleku (3,2-odstotna), koruznih zrnih (10-odstotna) in arašidih (25-odstotna) [5]. Sojine proteine uporabljajo za prehrano ljudi in krmo živali, v industriji pa za lepila, emulzije, črnila, za farmacevtske izdelke, plastiko in tudi za tekstilna vlakna. Čedalje pomembnejši postajajo za proizvodnjo biorazgradljivih folij, kjer rešujejo problem absorpcije vode oziroma nizke trdnosti v mokrem z zamreženjem proteinov s palmovo ali stearinsko kislino [6] ali tudi z dodajanjem polivinilalkohola [7].

Aminokislinska sestava sojinih beljakovin (preglednica 1) je bolj podobna aminokislinski sestavi keratina kot fibroina (slika 1). V sojinih beljakovinah sta zastopani aminokislini izolevcin in histidin, ki ju v volnenem keratinu ni. Cistinskih vezi kot pomembnih medmolekulskih kovalentnih vezi med peptidnimi molekulami v keratinu pa skoraj ni v sojinih beljakovinah, saj vsebuje manj kot 0,1 % cistina. V sojinih proteinih so aminokisline s kislim značajem z izrazitim negativnim nabojem (31,63 %), aminokisline z bazičnim značajem (24,05 %), ki imajo pozitivni naboj in vežejo molekule z negativnim nabojem, in nepolarne beljakovine (37,06 %) (slika 1). Sojini proteini so najbolj topni v območju pH od 1,5 do 2,5 in nad pH 6,3. Najmanj topni so v območju pH od 3,75 do 5,25, še posebej ne v območju izoelektrične točke, pri pH od 4 do 5.

Sojine proteine sestavljajo globulini (pribl. 90 %) in albumini. Globulini so visokih molekulskih mas in težko topni v vodi, topni so v razredčenih solnih raztopinah, albumini so nizkih molekulskih mas in so vodotopni [8]. Za oblikovanje vlaken uporabljajo globularne proteine, v katerih prevladujeta β-konglicinin (30–50 % proteinov v semenu) in glicinin (30 % proteinov v semenu). β-konglicinin je heterogen glikoprotein, sestavljen iz treh podenot (α‘, α, β), ki vsebujejo aminokisline asparagin, glutamin, arginin in levcin. Podenote so nekovalentno povezane z elektrostatičnimi interakcijami in vodikovimi vezmi brez disulfidnih vezi. Glicinin je večji heksamer, ki ga sestavljajo kisli in nevtralni polipeptidi [9].

Table 1: Amino acids content in soybean protein in comparison to wool keratin and silk fibroin

Amino acid	–R (organic substituent)	Chemical nature	Soya [10]	Wool [11]	Silk [12]
Glutamic acid / Glutamine	$-(CH_2)_2-COOH$ / $-(CH_2)_2-CO-NH_2$	acidic	18.11	16	1.0
Aspartic acid / Asparagine	$-CH_2-CO-OH$ / $-CH_2-CONH_2$	acidic	11.33	7.27	1.3
Leucine	$-CH_2-CH(CH_3)_2$	nonpolar	8.4	9.7	0.5
Serine	$-CH_2-OH$	basic	6.34	9.5	12.1
Proline		nonpolar	6.33	7.2	0.4
Arginine		basic	5.56	3.6	0.5
Lysine	$-(CH_2)_4-NH_2$	basic	5.50	2.5	0.3
Phenylalanine		nonpolar	5.3	1.6	0.6
Alanine	$-CH_3$	nonpolar	4.12	4.1	29.4
Valine	$-CH(CH_3)_2$	nonpolar	4.5	5.5	2.2
Threonin		basic	4.01	6.6	0.9
Histidine		acidic	2.19	0.7	0.1
Tryptophan		nonpolar	1.5	0.7	0.1
Glycine	-H	nonpolar	0.23	6.5	44.6
Tyrosine		basic	2.64	6.1	5.2
Isoleucin		nonpolar	4	0	0.7
Methionin	$-(CH_2)_2-S-CH_3$	nonpolar	2	0.35	0.1
Cysteine	$-CH_2-SH$	nonpolar	0.68	11.3	0.2

between peptide molecules in keratin. Namely, the content of cystine in soybean proteins is under 0.1%. Soybean proteins contain amino acids of acidic nature with pronounced negative charge (31.63 %), amino acids of basic nature (24.05%), which have positive charge and attract oppositely charged molecules, and non-polar proteins (37.06%) (Figure 1). Soybean proteins are most soluble within pH range from 1.5 to 2.5 and above pH 6.3, and least soluble within pH range from 3.75 to 5.25 while being practically insoluble in the zone of izoelectric point at pH 4 to 5.

Soybean proteins are composed of globulins (about 90%) and albumins. Globulins are the proteins with high molecular weight, hardly soluble in water, but soluble in diluted salt solutions, while albumins are the proteins with low molecular weight and soluble in water [8]. Proteins, which are used for fibres formation, are globular proteins with predominant β-conglycinin (30–50% of seed proteins) and glycinin (30% of seed proteins). β-conglycinin is a heterogenous glycoprotein composed of three subunits (α', α, β), which contain amino acids asparagines, glutamine, arginine and leucine. Subunits are non-covalently linked by electrostatic interactions and hydrogen bonds without any disulphide bonds. Glycinin is a large hexamere composed of acidic and neutral polypeptides [9].

Peptide segments in globular soybean proteins are interconnected by hydrogen bonds and electrostatic interactions. Conformational modifications of globular soybean proteins during the process of denaturation, which means the modifications of quaternary, tertiary and secondary structure of proteins, and reduction of the inclination of denatured proteins to form aggregates are important for the preparation of a stabile and properly viscous spinning dope as well as for drawing, orienting and crystallizing proteins in formed fibres [9]. Denaturation of soybean proteins is induced by alkalis, heat and enzymes. Alkalis can also initiate the depolymerisation of molecules by cleaving amide bonds. The process of controlled denaturation of proteins is therefore highly important for the mechanical properties of soybean fibres, particularly for their tensile strength. Unfavourable conditions in terms

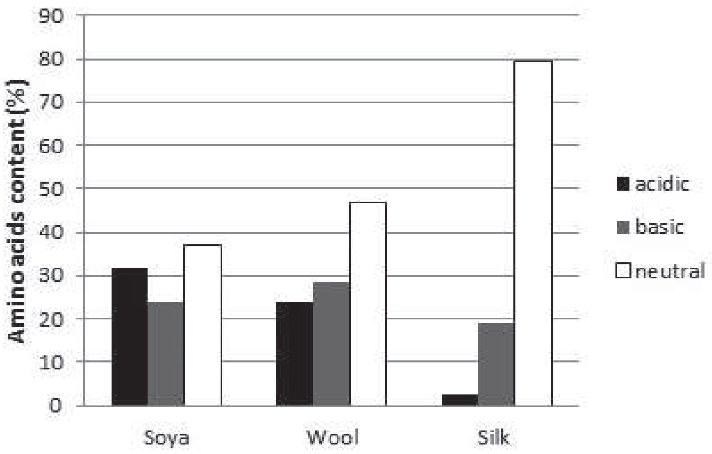


Figure 1: Content of acidic, basic and neutral amino acids in soybean proteins, keratin of wool and silk fibroin

Peptidni segmenti v globularnih proteinih soje so med seboj povezani prek vodikovih vezi in elektrostatskih interakcij. Konformacijske spremembe globularnih sojinih proteinov v procesu denaturacije, tj. modifikaciji kvarterne, terciarne in sekundarne strukture proteinov, [9] in zmanjšanje nagnjenosti denaturiranih proteinov k agregiranju so pomembne za pripravo stabilne in primerno viskozne predilne tekočine in za proces raztezanja, orientiranja in kristalizacije proteinov v oblikovanih vlaknih. Denaturacijo sojinih proteinov povzročijo alkalije, toplota in encimi. Alkalije lahko povzročijo tudi depolimerizacijo molekul s cepitvijo amidnih vezi. Zato je proces kontrolirane denaturacije beljakovin zelo pomemben za mehanske lastnosti sojinih vlaken, predvsem za natezno trdnost, saj pri denaturaciji zaradi neustreznih pogojev temperature, pH vrednosti, koncentracije soli, sečnine, organskih topil in redukcijskih sredstev nastopita degradacija proteinov in sprememba barve.

Za zmanjšanje nagnjenosti proteinskih molekul k agregiranju je Boyer [13] predlagal dodatek ksantata, ki reagira z aminoskupinami proteinov in tvori karboaminditio skupine (NHCSSH). Disulfidna vez, ki tako nastane, ni medmolekulska in vpliva predvsem na zmanjšanje viskoznosti predilne tekočine.

Ni naključje, da je bil kot sintetični polimer za izdelavo novih sojinih proteinskih vlaken najustreznejši polivinilalkohol, saj je postopek za izdelavo PVAL-vlaken podoben kot za izdelavo proteinskih vlaken: v podobnih razmerah vlakna izpredajo iz raztopin, koagulirajo v obarjalni kopeli, orientirajo z raztezanjem in zamrežijo. Zamreženje zmanjša vezanje vode in trdnost vlaken v mokrem. Med danes sprejemljivimi zamreževalnimi postopki je zamreženje prek aminoskupin v proteinu z anhidridom ocetne kisline (acetiliranje) ali z glutaraldehidom.

Surovina za izdelavo SPF-vlaken so sojini kosmiči, stranski produkt po ekstrakciji olj in drugih maščobnih substanc [14]. Ekstrahirane sojine beljakovine najprej za 2–2,5 ure namočijo v alkal-

of temperature, pH value, concentration of salt, urea, organic solvents and reduction agents in the process of denaturation can induce the degradation of proteins and the change of colour.
In order to decrease the inclination of protein molecules to form aggregates, Boyer [13] proposed the addition of xanthate, which reacts with the amino groups of proteins and forms the carboaminditio groups (-NHCSSH). The resulting disulphide bond is not an intermolecular bond and its effect is mainly limited to the reduction of the spinning dope viscosity.
It is not a coincidence that polyvinyl alcohol has been found the most suitable synthetic polymer for the manufacture of new soybean protein fibres. Namely, the process of manufacturing PVAL fibres is similar to that of protein fibres: under similar conditions fibres are spun from solution, coagulated in a precipitating bath, oriented by drawing and crosslinked. Due to crosslinking, the water absorbency and decrease of the strength of fibres in wet state have been reduced. Today acceptable crosslinking processes include the crosslinking through amino groups in protein by acetic anhydride (acetylation) or glutaraldehyde.

ni raztopini pH 8,4 pri temperaturi 50–50 °C, da dobijo raztopino s koncentracijo sojinih beljakovin okrog 15 %. Sočasno pripravijo 8–15-% raztopino polivinilalkohola (PVA) v destilirani vodi pri temperaturi 79–97 °C za 100 min. Dobljeni raztopini zmešajo v določenem razmerju pri temperaturi 80–95 °C v času 40 min. Pripravljeno predilno tekočino pustijo zoreti 180–200 min pri temperaturi med 50 in 70 °C, da se odzrači in filtrira, nato sledi oblikovanje vlaken po mokrem postopku. Oblikovanje vlaken poteka s hitrostjo okrog 30 m/min. V koagulacijski žvepleno kisli kopeli temperature 30–36 °C in ob dodatku Na_2SO_4 nastane filamentni kabel, ki ga raztezajo na zraku in v vodni raztopini Na_2SO_4 pri temperaturi 43,5–55 °C. Termofiksiranje raztezanih filamentov poteka skozi pet komor s temperaturami 121/211/228/240/230 °C. Sledijo acetiliranje, pranje, nanos preparacije in rezanje. [4]
Obstaja več variacij opisanega postopka, z razlikami v načinu priprave predilne tekočine, predilnih hitrostih, koncentracijah in temperaturah.
V oblikovanih vlaknih se molekule proteinov prečno povežejo z molekulami polivinilalkohola prek vodikovih vezi, kar omogoča orientacijo in kristalizacijo proteinov med procesom raztezanja. Morfološko strukturo vlaken predstavljata manj orientiran plašč in dobro orientirano mikrofibrilno jedro. Vlakna vsebujejo okrog 10 % hidrofilnih skupin v amorfnih območjih [15], ki dobro vežejo zračno vlago. V preglednici 2 so podane fizikalne in kemijske lastnosti novih sojinih proteinskih vlaken v primerjavi z bombažem, viskoznimi vlakni, svilo in volno.

Table 2: Comparison of physical and chemical properties of new soybean protein fibres (SPF) in comparison to cotton, viscose, silk and wool [1]

Properties	SPF	Cotton	Viscose	Silk	Wool
Specific breaking strength (cN/dtex) in dry state	3.8–4.0	1.9–3.1	1.5–2.0	2.6–3.5	0.9–1.6
Specific breaking strength (cN/dtex) in wet state	2.5–3.0	2.2–3.1	0.7–1.1	1.9–2.5	0.7–1.3
Breaking elongation (%) in dry state	18–21	7–10	18–24	14–25	25-35
Initial modulus (MPa)	700–1300	850–1200	850–1150	650–1250	
Loop strength (%)	75–85	70	30–65	60–80	
Knot strength (%)	85	92–100	45–60	80–85	
Moisture regain (%)	8.6	8.5	13.0	11.0	14–16
Density (g/cm³)	1.29	1.50–1.54	1.46–1.52	1.34–1.38	1.33
Heat resistance	Yellowing and tackifying at about 120 °C (Bad)	Becoming brown after long time processing at 150 °C (Excellent)	Strength down after long time processing at 15 °C (Good)	Keep stable when temperature ≤148 °C (Good)	(Good)

Continuation of Table 2.

Properties	SPF	Cotton	Viscose	Silk	Wool
Alkali resistance	At general level	Excellent	Excellent	Good	Bad
Acid resistance	Excellent	Bad	Bad	Excellent	Excellent
Ultraviolet resistance	Good	At the general level	Bad	Bad	Bad

The raw material for soybean protein fibres is soybean flakes, a by-product remaining after the extraction of oils and other fat substances [14]. The extracted soybean proteins are first soaked for 2–2.5 hours in alcohol solution with pH 8.4 and temperature between 40 and 50 °C in order to obtain a solution with the soybean proteins concentration about 15%. At the same time the 8–15% solution of polyvinyl alcohol (PVA) in distilled water with temperature 79–97 °C is prepared for 100 minutes. The obtained solutions are mixed at a pre-determined ratio at temperature 80–95 °C for 40 minutes. The prepared spinning dope is left to mature for 180–200 minutes at temperature between 50 and 70 °C to be released of air and filtrated. The next stage is the formation of fibres by using the wet spinning procedure. The formation of fibres proceeds with the velocity of approximately 30 m/min. In a coagulation sulphuric acid bath with temperature 30–36 °C and with the addition of Na_2SO_4, a filament cable is formed which is then drawn in the air and in the water solution of Na_2SO_4 with temperature 43.5–55 °C. Thermo-setting of drawn filaments proceeds through five chambers with temperatures 121/211/228/240/230°C. After that, the filaments are subjected to acetylation, scouring and application of finishing agents [4].

The described process has several variants, which differ in the method of spinning dope preparation, spinning velocities, concentrations and temperatures.

In the formed fibres the molecules of proteins link crosswise with the molecules of polyvinyl alcohol by hydrogen bonds, which enables orientation and crystallization of proteins during the process of drawing. The morphological structure of fibres is composed of a less oriented sheath and a well-oriented microfibrillar core. The fibres contain about 10% of hydrophilic groups in

Po vezanju zračne vlage SPF-vlakna dosegajo bombaž, v mokrem se jim za dobro četrtino zmanjša natezna trdnost, na 2,5–3,0 cN/dtex, kar je primerljivo z bombažem srednje kakovosti. Po vezanju zračne vlage so primerljiva z bombažem, vendar gre v nasprotju z bombažem za termoplastično vlakno z veliko občutljivostjo pri temperaturah nad 100 °C. Njihova prednost je dobra obstojnost v kislinah in alkalijah (razen v natrijevem hidroksidu) in na sončni svetlobi.

Sojini proteini so poceni in obnovljiv surovinski vir. Ekološko sprejemljivost pomenijo možnosti biorazgradnje SPF-vlaken, kar naj bi nova sojina proteinska vlakna tudi bila [16]. Sojine beljakovine, ki jih je v SPF-vlaknih 5–23 %, razgradijo mikroorganizmi in encimi. Peptidne vezi v beljakovinah so zelo občutljive na razgradnjo z encimi. Biorazgradnja proteinov do CO_2 in vode poteče šele po predhodni hidrolizi peptidnih vezi v proteinih. Pri tem se večje makromolekule pretvorijo v manjše, ki jih metabolizmi mikroorganizmov lahko predelajo. Ker vsebujejo sojine beljakovine zelo majhen odstotek cistina (0,1 %), so tako rekoč skoraj neobčutljive na encime, kot so proteaze, esteroze, lipaze in vse, ki specifično delujejo na disulfidno vez. Polivinilalkohol, ki ga je v SPF-vlaknih 77–95 %, je edini znani vodotopni in biorazgradljivi sintetični polimer. V celoti ga razgradijo bakterije *Pseudomons* O–3. Več sevov bakterij *Pseudomonas*, ki lahko razgradijo PVA, so našli v zemlji, čeprav je biorazgradnja PVA v zemlji zelo omejena. Mikroorganizmi, ki razgradijo PVA, so prisotni skoraj izključno v okoljih, ki so ves čas kontaminirana s polimerom PVA [17]. Encimi dehidrogenaze in oksidaze razgradijo vezi C–C v PVA-molekuli [18].

Raziskave o poteku aerobne biorazgradnje kompozitnih filmov iz sojinih proteinov in z dodatkom 10–30 % PVA so pokazale, da se je z večanjem deleža PVA podaljšal čas biorazgradnje kompozitnega filma [19]. PVA, ki ga dodajajo za izboljšanje mehanskih lastnosti v mokrem, zmanjša hidrofilnost filma in s tem tudi upočasni njegovo biorazgradnjo. Lahko pa PVA pomeni pregrado, ki prepreči dostop mikroorganizmom, encimom, vlagi ali kisiku v polimer [20].

Poleg zunanjih pogojev biorazgradnje (prisotnost ustreznih encimov in mikroorganizmov, ustrezna temperatura, vlažnost in pH vrednost) je biološki proces razgradnje odvisen tudi od morfološke strukture (kristaliničnosti) in ostankov pomožnih sredstev, ki so se med proizvodnjo nakopičila na/v materialu in jih ni mogoče popolnoma izprati med končno obdelavo [21].

amorphous regions [15], which absorb the moisture well. Table 2 presents physical properties of new soybean protein fibres in comparison with cotton, viscous, silk and wool fibres.

In respect of moisture regain, SPF can compete with cotton fibres, however, in wet state their specific breaking stress decreases by approximately 25% to 2.5–3.0 cN/dtex, which is comparable to a medium quality cotton. In respect of moisture regain, SPF can be compared with cotton fibres, but unlike cotton fibres, they are thermoplastic with high sensitivity to temperatures above 100 °C. Their advantage is good stability in acids and alkalis (except in sodium hydroxide) and under sunlight.

Soybean proteins are cheap and renewable raw material. Considering the capacity of soybean proteins and polyvinyl alcohol to decompose, new soybean fibres are supposed to be biodegradable and therefore ecologically acceptable [16]. Soybean protein fibres contain about 5–23% of soybean proteins, which are decomposed by microorganisms and enzymes. Peptide bonds in proteins are especially susceptible to enzymatic degradation. The biodegradation of proteins to CO_2 *and water takes place after previous hydrolysis of peptide bonds in proteins during which large macromolecules transform into smaller ones that can be broken down by the metabolism of microorganisms. Since soybean proteins contain a very low percentage of cystine (0.1%), they are practically insusceptible to enzymes, such as proteases, esterases, lipases and all others, which have a specific effect on disulfide bonds. Polyvinyl alcohol, represented in soybean protein fibres with a 77–95% share, is the only known water soluble and biodegradable synthetic polymer. It is completely degraded by Pseudomonas O–3 bacteria. Several strains of these bacteria, which can degrade PVA, have been found in the soil although biodegradation of PVA in the soil is very restricted. Microorganisms, which degrade PVA, are present almost exclusively in the environments, which are constantly contaminated with PVA polymer [17]. The enzymes of dehydrogenase and oxidase degrade C–C bonds in a PVA molecule [18].*

The study of the course of aerobic biodegradation of composite films made from soybean pro-

V raziskavi so nas zanimale lastnosti tekstilij, ki vsebujejo sojina proteinska vlakna, predvsem njihova nagnjenost k biorazgradnji takšne tekstilije kot celote. Takšne mešanice so glede na kombiniranje lastnosti celuloze, beljakovin in polivinilalkohola zanimive z vidika udobnosti nošenja oblačil [22] in vzdrževanja. Objavljenih raziskav o biorazgradljivosti novih sojinih proteinskih vlaken ni.

2 Eksperimentalni del

2.1 Materiali

V raziskavi smo proučevali obnašanje predivnih prej in tkanin z novimi sojinimi proteinskimi vlakni v razmerah kontrolirane biorazgradnje:

- preja SPF iz 100-odstotno novih sojinih proteinskih vlaken, finoče 15 tex (Harvest SPF Textile Co., Ltd.)
- preja CO iz 100-odstotnega bombaža, finoče 19 tex
- tkanina CO/SPF iz preje iz 100-odstotnega bombaža, finoče 28 tex v osnovi in iz preje SPF v votku, vezava keper 2/2
- tkanina CO iz 100-odstotne bombažne preje, finoče 28 tex, vezava keper 2/2.

Oba vzorca tkanin sta imela gostoto po osnovi 30 niti/cm in 28 niti/cm po votku.

2.2 Uporabljene metode

Laboratorijski poskusi biorazgradnje so bili opravljeni v skladu s standardom SIST EN ISO 11721-1 [23]. Uporabljena je bila tržna zemlja (humus), bogata z mikroorganizmi. Vlažnost zemlje v območju 60 ± 5 % smo med poskusom vzdrževali z rednim vlaženjem z vodo iz vodovoda. Temperatura zemlje je bila 25–30 °C, pH 6. Vzorce prej in tkanin smo sočasno zakopali v zemljo in jih postopno po 2., 7., 11., 16. in 21. dnevu odkopali ter pred nadaljnjim proučevanjem najprej oprali v vodi ter za 30 minut namočili v etanolu, da smo ustavili aktivnost mikroorganizmov. Nato smo vzorce posušili na zraku.

Natezne lastnosti vzorcev smo izmerili na dinamometru Instron 5567, kot določa standard SIST EN ISO 2062 za preje in SIST EN ISO 13934 za tkanine. Pred merjenjem nateznih lastnosti preje v mokrem stanju smo le-te namakali v destilirani vodi z dodatkom omakalnega sredstva eno uro pri sobni temperaturi. Natezne lastnosti prej smo analizirali s programom DINARA [24].

S pomočjo vrstičnega elektronskega mikroskopa Jeol JSM 6060 LV in stereomikroskopa Nikon SMZ 800 smo opazovali in posneli videz vlaken, prej in tkanin pred poskusom biorazgradljivosti vzorcev v zemlji in po njem.

Kemično zgradbo sojinih proteinskih vlaken smo proučevali s pomočjo spektrov FTIR/ATR na napravi Spectrum GX (Perkin Elmer), ki je bil opremljen z Michelsonovim interferometrom in programsko opremo Spectrum 5.01.

teins with addition of 10–30% of PVA have revealed that the higher is the percentage of PVA the longer is the time of biodegradation of a composite film [19]. PVA, which is added in order to enhance mechanical properties in wet state, reduces the hydrophilicity of such film and, consequently, retards its biodegradation. PVA can also represent a barrier, which prevents microorganisms, enzymes, moisture and oxygen to penetrate into a polymer [20].

Besides external conditions (the presence of suitable enzymes and microorganisms, proper temperature, humidity and pH value), the biodegradation process depends also on the morphological structure (crystallinity) and quantity of residual auxiliary agents, which have adhered to the material during production and cannot be removed completely during the finishing process [21].

The study focused on the properties of textiles containing soybean protein fibres, particularly to their inclination to biodegrade as a whole. In terms of wearing comfort, such blends, due to the combination of the properties of cellulose, proteins and polyvinyl alcohol, are very interesting for thermal comfort and care of garments [22]. No researches about the biodegradability of new soybean protein fibres have been published until now.

3 Rezultati in razprava

Preja iz 100-odstotnih SPF je bila izdelana iz vlaken bombažnega tipa, finoče 1,27 dtex in povprečne dolžine 39,5 mm. Prečni prerez vlaken je ledvičasto-fižolaste oblike, premer 11–20 µm po večji diagonali in 6–7 µm po manjši diagonali (slika 2). Zaradi gladkega površja imajo vlakna visok lesk. Na površju vlaken so vidne manjše brazde. Vlakna so termoplastična s tališčem pri 224 °C.

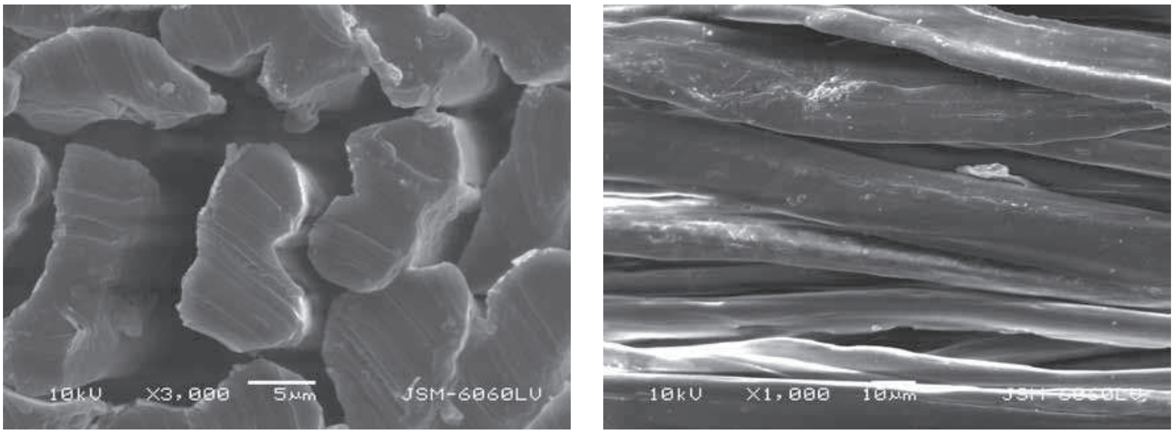


Figure 2: Scanning electron microscope views of raw SPF: cross section (magnification 3000-x) and longitudinal view (magnification 1000-x)

Znano je, da imajo proteini tipične absorpcijske vrhove v območju frekvenc 1636–1680 cm^{-1} in 1533–1559 cm^{-1}, ki izvirajo iz peptidnih vezi v glavnih verigah beljakovinskih molekul in tudi iz absorpcije medmolekulskih interakcij, ki izvirajo iz sekundarne, terciarne in kvartarne strukture proteinov in se med seboj prekrivajo. FT-IR-spekter SPF vlaken (slika 3a) kaže absorpcijo pri frekvenci 1642,47 cm^{-1}, ki jo lahko pripisujemo vibracijam –NH– vezi v amidu I, pri frekvenci 1534,94 cm^{-1} pa vibracijam –NH– vezi v amidu II. Absorpcijski pas pri frekvencah 1241–1472 cm^{-1}, ki je prisoten tudi pri spektru SPF-vlaken, pripisujejo raztezanju vezi (C)O–O in C–N ter upogibanju vezi N–H v amidnih III skupinah [19]. FT-IR-spekter čistih PVAL-vlaken Kuralon (Kuraray Co., Ltd.) ima značilen absorpcijski vrh pri frekvenci 3292 in ustreza raztezanju vezi v skupinah O–H [19]. Obstoj vodikovih vezi med peptidnimi molekulami soje in molekulami PVA je teže ugotoviti, saj se absorpcija teh vezi prekriva z absorpcijo vodikovih vezi med vodo in proteinskimi oziroma PVA-molekulami, kar je mogoče prepoznati v širšem absorpcijskem pasu (slika 3a) [19] pri frekvencah 2918–3565 cm^{-1}.

Absorpcijski spektri ATR FT-IR SPF-vlaken (slika 3b), ki odražajo kemično zgradbo v površinski plasti SPF-vlaken, kažejo na zmanjšanje intenzitete absorpcijskih vrhov za SPF-vlakna, ki so bila 11 oziroma 21 dni zakopana v zemlji. Izrazitejše zmanjšanje intenzitete vrha v frekvenčnem območju 3000–3600 cm^{-1} je opaziti le po prvih 11 dneh. To pripisujemo kemičnim spremembam, ki so po-

2 Experimental part

2.1 Materials

The study focused on the behaviour of spinning yarns and fabrics made from new soybean protein fibres under the conditions of controlled biodegradability:

- *SPF yarn from 100% new soybean protein fibres with linear density 15 tex (Harvest SPF Textile Co., Ltd.),*
- *CO yarn from 100% cotton with linear density 19 tex,*
- *CO/SPF fabric from 100% cotton with linear density 28 tex in warp and SPF yarn in weft, 2/2 twill weave,*
- *CO fabric from 100% cotton yarn with linear density 28 tex, 2/2 twill weave.*

Both fabric samples had the warp density 30 ends/cm and weft density 28 picks/cm.

2.2 Used methods

Laboratory experiments were performed in compliance with SIST EN ISO 11721-1 standard [23]. Commercial soil (humus), rich with microorganisms, was used in experiments. The soil humidity 60±5% was maintained during experiments by regularly spraying the soil with tap water. The temperature of soil was 25–30 ˚C and its pH 6. The samples of yarns and fabrics were buried in the soil at the same time and then gradually removed from the soil after 2, 7, 11, 16 and 21 days. Prior to further experiments, the samples were washed in water and immersed in ethanol for 30 minutes in order to stop the activity of microorganisms, and after that the samples were air-dried.

Tensile properties of the samples were measured on Instron 5567 dynamometer in compliance with SIST EN ISO 2062 standard for yarns and SIST EN ISO 13934 standard for fabrics. Prior to making any measurements of the yarn tensile properties in wet state, the yarns were immersed in distilled water with added wetting agent for 1 hour at room temperature. The tensile properties of yarns were analysed by using DINARA program [24].

The appearance of fibres, yarns and fabrics was monitored and photographed by Jeol JSM 6060 LV scanning electron microscope and Nikon SMZ 800 stereomicroscope prior to testing bio-

vezane z zmanjšanjem števila vodikovih vezi med molekulami protein–protein, PVA–PVA in protein–PVA, kar je omogočilo dezorientacijo segmentov v amorfnih območjih.

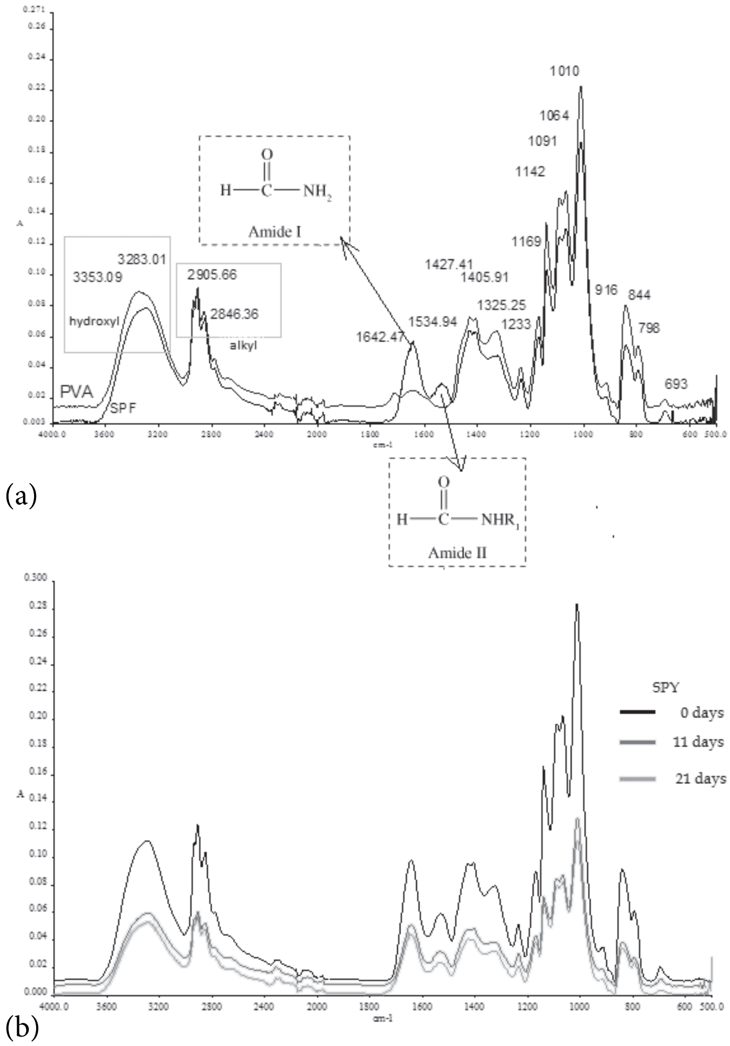


Figure 3: FT-IR spectra of SPF and PVAL fibres (a) and of burried SPF yarns (SPY) for 0, 11 and 21 days (b)

Voda vpliva na natezne lastnosti prej iz 100-odstotno sojinih proteinskih vlaken: v suhem stanju je imela preja specifično pretržno napetost 2,16 cN/dtex, v mokrem pa le 1,58 cN/dtex. Raztegljivost preje se je v mokrem stanju povečala, posledica tega pa sta nižji modul elastičnosti in višji pretržni raztezek, ki je znašal 37,8 % v suhem in 42,1 % v mokrem stanju.

Obnašanje prej iz SPF-vlaken smo proučevali po 2., 7., 11., 16. in 21. dnevu zakopa v zemlji pri temperaturi zemlje 30 ˚C, relativni vlagi 65 % in pH 6. Biorazgradnja bombažne preje je skoraj v celoti potekla že v sedmih dneh, ko so v zemlji ostali le manjši nepovezani deli preje. Po 11 dneh je bila bombažna preja popolnoma razgrajena brez vidnih ostankov v zemlji. Zato smo natezne lastnosti *degradation in the soil and after it.*

The chemical structure of soybean protein fibres was investigated by means of FTIR/ATR spectra on the Spectrum GX (Perkin Elmer) equipped with the Michelson interferometer and Spectrum 5.01 software.

bombažne preje lahko izmerili le po prvem odvzemu prej iz zemlje, to je po dveh dneh.

Sojina proteinska vlakna imajo na površju manjše brazde, v katerih se mikroorganizmi laže zadržijo kot na gladkem površju, in tudi lahko vstopijo globlje v vlakna. Količina mikroorganizmov, ki so prisotni na površju sojinih proteinskih vlaken po 21 dneh zadrževanja preje v zemlji (slika 4), je majhna, predvsem pa še ni opaziti poškodb površja vlaken.

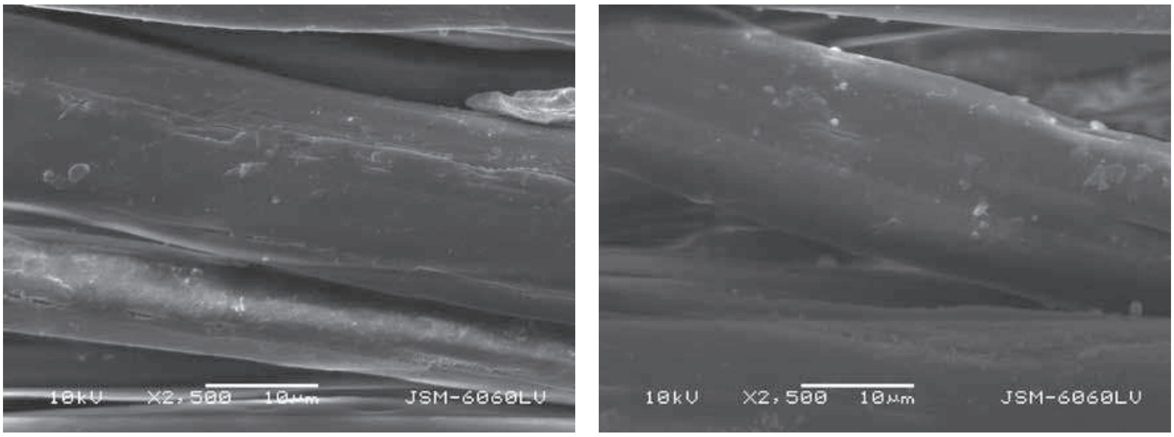


Figure 4: Scanning electron microscope views of SPF fibres before (left) and after 21 days (right) in the soil

3 Results and discussion

Pure SPF yarn was made from cotton-type fibres with linear density 1.27 dtex and mean length 39.5 mm. The cross-section of fibres was bean-shaped with diameter 11–20 μm along the longer diagonal and 6–7 μm along the shorter diagonal (Figure 2). Smooth surface imparted high lustre to the fibres. Small grooves could be noticed on the surface. The fibres had thermoplastic character with melting point at 224 °C.

It is known that proteins have typical absorption peaks within the range of frequencies 1636–1680 cm^{-1} and 1533–1559 cm^{-1} attributable to peptide bonds in the backbone of protein molecules as well as to the absorption of intermolecular interactions which arise from the secondary, tertiary and quaternary structure of proteins and overlap each other. The FT-IR spectrum of soybean protein fibres (Figure 3a) displays the absorption at frequency 1642.47 cm^{-1}, which can be attributed to the vibrations of –NH– bonds in amide I, and at frequency 1534.94 cm^{-1}, which can be attributed to the vibrations of –NH– bonds in amide II. The absorption band at frequencies 1241–1472

Spremembe v mehanskih lastnostih prej po zadrževanju v zemlji so prikazane v preglednici 3. Pretržna sila bombažne preje se je po dveh dneh zmanjšala skoraj za 40 %, pretržni raztezek pa za skoraj 35 %. Mehanske lastnosti preje iz sojinih proteinskih vlaken se po 21 dneh niso bistveno spremenile: pretržna sila se je zmanjšala le za 1,6 %, pretržni raztezek pa za odstotek. Sklepamo, da se po 21 dneh v zemlji še ni začela biorazgradnja SPF-vlaken.

Tkanine so bile sočasno pri enakih razmerah kot preje zakopane v zemljo za 2, 7, 11, 16 in 21 dni. S časom zakopa v zemlji se jim je spreminjal videz: na površju so nastajali rjavkasti madeži zaradi razvoja kolonij gliv na vlaknih (slika 6). Pri vseh tkaninah smo opazili tanjšanje preje iz čistega bombaža s časom zakopa. Sprememba debeline bombažnih niti je dobro vidna (slika 5). Na bombažni tkanini so po 11 dneh že opazne spremembe v obliki zrahljanja povezav med prejami, po 16 in še bolj po 21 dneh pa so že vidne poškodbe in raztrganine v tkanini iz 100-odstotnega bombaža. V enakem času so tkanine s prejo iz SPF-vlaken v votku ohranile nepoškodovan, le rahlo zrahljan videz.

Tkanina iz čistega bombaža je po enem tednu izgubila mehansko trdnost in je ob dotiku razpadala. Po 21 dneh so od nje ostali le še majhni, nepovezani fragmenti. Tkanina, ki je imela v votku prejo iz sojinih proteinskih vlaken, je počasneje razpadala kot tkanina iz čistega bombaža in je počasneje izgubljala trdnost. Zaradi hitrega razpada so se bombažne preje v smeri osnove tanjšale in tkanine so se s časom čedalje bolj trgale v smeri votka.

Table 3: Breaking force and breaking elongation of CO and SPF yarns buried in soil

day	Breaking force						Breaking elongation					
	Cotton yarn			Soybean protein yarn			Cotton yarn			Soybean protein yarn		
	average (cN)	min.-max (cN)	CV (%)	average (cN)	min.-max (cN)	CV (%)	average (%)	min.-max (%)	CV (%)	average (%)	min.-max (%)	CV (%)
0	265.07	194.83–295.02	8.57	281.30	237.40–319.38	8.29	4.63	3.78–5.55	11.23	17.37	15.10–18.63	5.07
2	159.16	96.14–234.42	23.78	267.61	198.34–322.00	14.49	3.01	2.27–4.53	21.45	15.77	12.59–17.39	8.5
7	–	–	–	267.94	216.83–308.22	9.11	–	–	–	15.99	14.63–17.38	4.25
11	–	–	–	276.24	242.17–322.28	8.06	–	–	–	16.18	14.62–17.90	5.1
16	–	–	–	278.91	228.07–310.16	6.66	–	–	–	15.94	13.11–18.14	6.37
21	–	–	–	276.76	237.57–313.84	7.76	–	–	–	16.38	14.87–17.64	4.69

cm^{-1}, which is present also in the spectrum of soybean protein fibres, is attributed to the stretching of bonds (C)O–O and C–N as well as to the bending of bonds N–H in amide III groups [19]. The FT-IR spectrum of pure PVAL fibres Kuralon (Kuraray Co., Ltd.) has a typical absorption peak at frequency 3292, which is attributed to the stretching of bonds in O–H groups [19]. It is much more difficult to ascertain whether hydrogen bonds exist between soybean molecules and PVA molecules as the absorption of these bonds overlaps with the absorption of hydrogen bonds between water and protein or PVA molecules which can be recognized in a wider absorption band (Figure 3a) [19] at frequencies 2918–3565 cm^{-1}.

The ATR FT-IR absorption spectra of soybean protein fibres (Figure 3b) reflecting the chemical structure in the soybean protein fibres surface layer exhibit the decrease in the intensity of absorption peaks of soybean protein fibres that were buried in the soil for 11 and 21 days. A much more pronounced peak decrease within the frequency range 3000–3600 cm^{-1} can be noticed after the first 11 days. This phenomenon can be attributed to chemical changes related with the decrease of the number of hydrogen bonds between protein–protein, PVA–PVA and

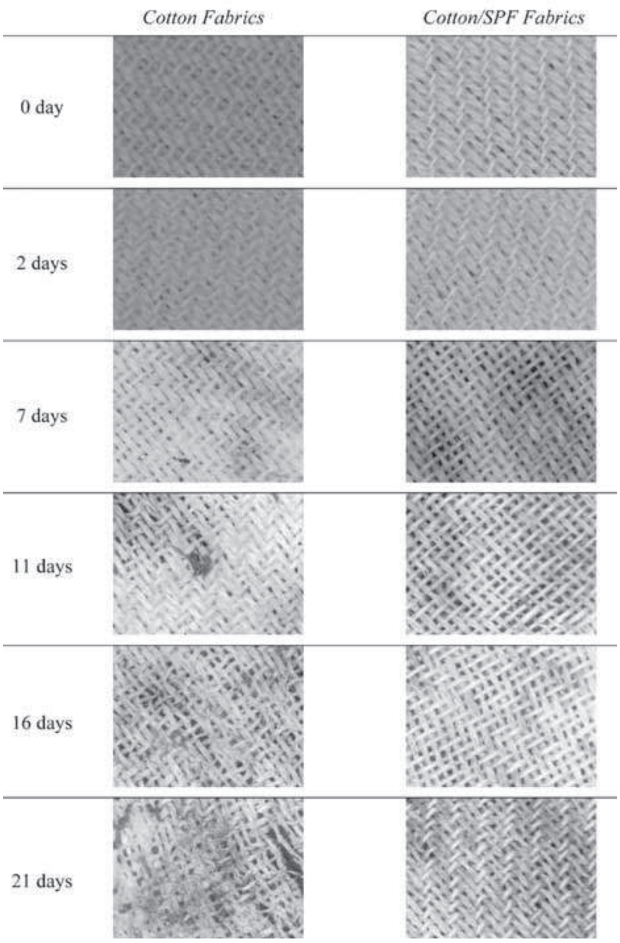


Figure 5: Surface views of burried fabrics in soil

protein–PVA molecules, which enables the disorientation of segments in amorphous regions.
Water affected the tensile properties of the yarns made from 100% soybean protein fibres: the specific breaking stress was 2.16 cN/dtex in dry state and only 1.58 cN/dtex in wet state. The elasticity of the yarn increased in wet state leading to a lower modulus of elasticity and higher breaking elongation, which was 37.75% in dry state and 42.05% in wet state.
The behaviour of the soybean protein fibres was investigated after 2, 7, 11, 16 and 21 days of having been buried in the soil with temperature 30 °C, relative humidity 65% and pH 6. Biodegradation of the cotton yarn was practically completed in the first seven days when only small separate particles of the yarn could be found in the soil. After 11 days the cotton yarn was completely degraded without any visible remains in the soil. Therefore, it was possible to measure the tensile properties of the cotton yarn only after the first removal from the soil, which means after two days.
Small grooves on the surface of soybean protein fibres make this surface much more favourable for the existence of microorganisms and their penetration deeply into the fibres than a smooth surface. After 21 days, the quantity of

Spremembe na površini tkanin so bile vidne po 21 dneh zadrževanja v zemlji (slika 6). Na bombažni tkanini smo opazili veliko kolonij gliv in bakterij, ki so opazne tudi na površju prej iz sojinih proteinskih vlaken. Prav tako je bil viden razpad bombažne preje ob sočasno nepoškodovani preji iz sojinih proteinskih vlaken.

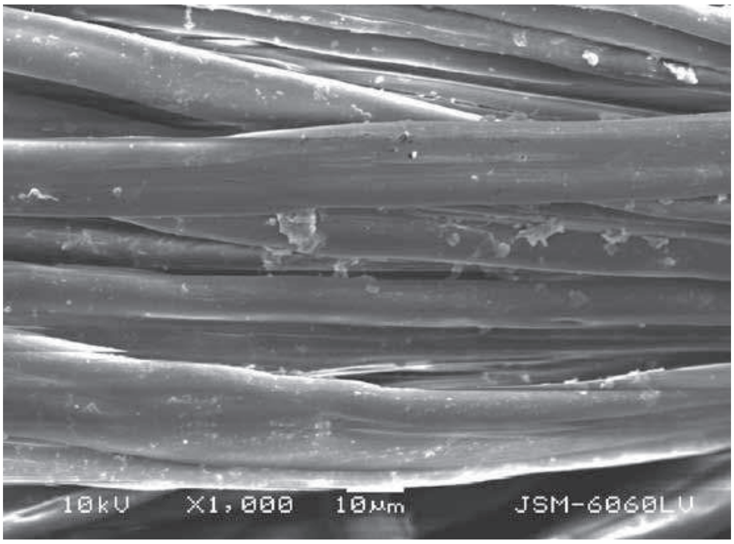


Figure 6: Scanning electron microscope photograph of soybean protein fibres after 21 days burried in soil (magnification 1000-x)

Tako kot preje je tudi tkanina CO razpadala veliko hitreje kot tkanina CO/SPF. Tkanini bombaž/sojina proteinska vlakna se je trdnost zmanjševala s časom zakopa v zemlji (slika 7). Pretržna sila

Table 4: Breaking force and breaking elongation of woven fabrics samples

	Breaking force						Breaking elongation					
	CO			CO/SPF			CO			CO/SPF		
day	average (N)	min.–max (N)	CV (%)	average (N)	min.–max (cN)	CV (%)	average (%)	min.–max (%)	CV (%)	average (%)	min.–max (%)	CV (%)
0	188.28	157.74–211.09	14.61	200.14	194.39–205.93	2.88	23.30	22.58–24.59	4.98	42.83	41.19–45.17	4.87
2	164.51	156.71–168.47	4.10	178.03	141.00–206.40	18.84	20.90	19.57–22.09	6.05	43.00	37.15–46.69	11.92
7	1.70	1.05–2.40	39.75	175.15	169.76–184.39	4.59	8.70	5.02–11.55	38.45	39.32	37.64–41.17	4.51
11	0		0	173.65	160.50–189.14	8.33	0		0	41.67	37.65–44.68	8.69
16	0		0	169.29	168.32–170.33	0.60	0		0	45.01	43.66–47.19	4.23
21	0		0	155.27	137.48–170.76	10.79	0		0	41.94	35.83–45.17	12.62

microorganisms on the surface of fibres (Figure 4) was small and, what is important, no damages on the surface could be noticed.

The changes of mechanical properties of the yarns buried in the soil are presented in Table 3. After 2 days of having been buried in the soil, the breaking force of the cotton yarn decreased by almost 40% and the breaking elongation by almost 35%. After 21 days of having been buried in the soil, the mechanical properties of the SPF yarn did not change substantially: the breaking force decreased by 1.6% only and the breaking elongation by 1% only. We can assume that the biodegradation of the soybean protein fibres did not already start after 21 days.

The fabric samples were buried in the soil for 2, 7, 11, 16 and 21 days at the same time and under the same conditions as the yarn samples. In dependence of how long the fabrics were buried in the soil, their appearance changed: brownish spots appeared on the surface due to the developing colonies of fungi on fibres (Figure 6). Thinning of the cotton yarns was noticed with all fabrics. The change of the thickness of cotton yarns is clearly visible (Figure 5). Certain changes, such as loosening of connections between yarns, could be noticed on the cotton fabric after 11 days. However, after 16 days and especially after 21 days, damages and tears were visible on the pure cotton fabric, while the CO/SPF fabric remained undamaged and had only a slightly loose appearance.

After one week the fabric made from pure cotton lost its mechanical strength and broke up into pieces when touched. After 21 days small, separate fragments remained from the fabric. The cotton/SPF fabric degraded at a slower rate than the cotton fabric, and also lost its strength at a slower rate. As a result of rapid degradation, the cotton yarns were getting thinner in warp direction and became prone to tearing in weft direction.

Changes on the surface of CO/SPF fabrics became visible after 21 days of having been buried in the soil (Figure 6). A great number of colonies of fungi and bacteria could be noticed on the surface of the cotton yarns as well as on the surface of the SPF yarns. The degradation of the cotton yarn was noticed, whereas the SPF yarn remained undamaged.

se je v smeri votka po sedmih dneh zmanjšala za 12 %, po 21 dneh pa za skoraj 22 % (krivulja SPF 21 na sliki 7). Razlog za zmanjšanje pretržne sile je predvsem razgradnja bombažne preje v smeri osnove in s tem zmanjšanje interakcij med osnovo in votkom, posledica tega pa je tudi manjši upor proti raztezanju tkanine v celotnem deformacijskem območju (nižji modul).

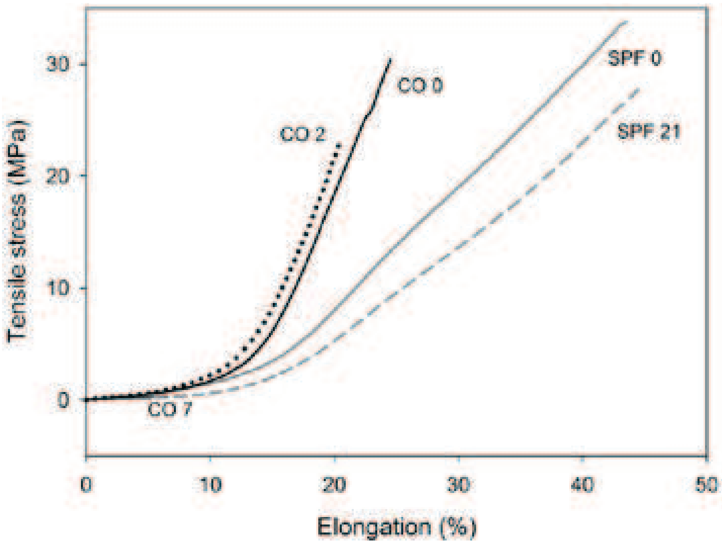


Figure 7: Stress-elongation curves for cotton (CO 0 = 0 days, CO 2 = 2 days, CO 7 = 7 days) and cotton/SPF (SPF 0 = 0 days, SPF 21 = 21 days) woven fabrics; all fabrics were measured in weft direction

4 Sklep

Nova sojina proteinska vlakna so bikonstituentna vlakna, izdelana po mokrem postopku iz homogene mešanice vodnih raztopin proteinov in polivinilalkohola. Vlakna vsebujejo le 5–23 % sojinih proteinov, ki so prek vodikovih vezi vezani na molekule polivinilalkohola. Imajo homogeno kemično sestavo. Vlakna so okolju prijazna, izdelana iz delno obnovljivih surovin, ki izvirajo iz ostankov predelave soje v olje.

V nasprotju s sojinimi proteinskimi vlakni iz 20. stoletja, ki so bila izdelana iz 100-odstotno sojinih proteinov, se nova sojina proteinska vlakna zaradi pretežnega deleža sintetičnega polimera polivinilalkohola odlikujejo po lastnostih, ki so značilne za sintetična vlakna: so termoplastična z dobrimi mehanskimi lastnostmi v mokrem.

Tekstilije iz SPF-vlaken in bombaža so z vidika uporabnih lastnosti tekstilij za oblačila ugodne, ker združujejo lastnosti celuloznih, beljakovinskih in sintetičnih vlaken.

Raziskava proučevanja obnašanja sojinih proteinskih vlaken v humusu je pokazala, da razmere, v katerih nastopi hitra biorazgradnja čistih bombažnih tekstilij, ne omogočajo biorazgradnje novih sojinih proteinskih vlaken. Po 21 dneh zadrževanja v rahlo kisli

The cotton fabric likewise the cotton yarns degraded at a faster rate than the cotton/SPF fabric. The strength of the cotton/SPF fabric decreased in dependence of the time spent in the soil (Figure 7). After 7 days the breaking force in weft direction decreased by 12% and after 21 days by almost 22% (SPF 21 curve in Figure 7). Such decrease can be attributed to the degradation of the cotton yarn in warp direction resulting in the decrease of interactions between warp and weft which leads to lower resistance of fabric to stretching in the entire deformation zone (lower modulus).

4 Conclusion

New soybean protein fibres are biconstituent fibres formed from a homogenous blend of water solutions of proteins and polyvinyl alcohol by wet spinning process. They contain only 5–23% of soybean proteins, which are linked to the molecules of polyvinyl alcohol by hydrogen bonds. Their chemical structure is homogenous. The fibres are eco-friendly, manufactured from partly renewable raw materials, which remain after soybean oil production.

Unlike soybean protein fibres known in the 20th century which were made from 100% soybean proteins, new soybean protein fibres, due to the predominant share of a synthetic polymer polyvinyl alcohol, excel in the properties typical for synthetic fibres: they are thermoplastic with good mechanical properties in wet state.

In respect of thermal comfort, the combination of the properties of cellulose, protein and synthetic fibres makes the textiles made from soybean protein fibres and cotton fibres interesting for the manufacture of garments.

The results of the study of soybean protein fibres behaviour in humus soil show that the conditions under which pure cotton textiles degrade rapidly do not induce the biodegradation of new soybean protein fibres. After 21 days of having been buried in a slightly acid (pH 6) soil with temperature 30 ˚C and relative humidity 65%, when the degradation of cotton fibres was practically completed, the mechanical properties and appearance of soybean protein fibres deteriorated only slightly.

(pH 6) zemlji pri temperaturi 30 ˚C in 65-odstotni relativni vlažnosti zemlje, ko so bombažna vlakna že skoraj v celoti razpadla, so se sojinim proteinskim vlaknom minimalno poslabšali mehanske lastnosti in videz površja.

5 Literatura

1. *SWICOFIL AG – Soybean protein fibres* [citirano 27. 04. 2011]. Dostopno na svetovnem spletu: <http://www.swicofil.com/soybeanproteinfiber.html>.
2. CIMILLI, S., NERGIS, B. U., CANDAN, C., ÖZDEMIR, M. A. comparative study of some comfort-related properties of socks of different fiber types. *Textile Research Journal*, 2010, vol. 80, p. 948–957.
3. LI, G. *Phytoprotein synthetic fibre and the method of making the same*. World Patent Office, WO/2003/056076, 2003.
4. LI, G. *Phytoprotein synthetic fibre and method of manufacture thereof*. United States Patent Office, US 7,271,217, 2007.
5. KRISHNAN, H. B., NATARAJAN, S. S., MAHMOUD, A. A., NELSON, R. L. Identification of glycinin and beta-conglycinin subunits that contribute to increased protein content of high-protein soybean lines. *J. Agric. Food Chem.*, 2007, vol. 55, p. 1839–1845.
6. LODHA, P., NETRAVAIL, A. N. Thermal and mechanical properties of environment-friendly 'green' plastics from stearic acid modified-soy protein isolate. *Industrial crops and products*, 2005, vol. 21, p. 49–64.
7. SU, J.-F., YUAN, X.-Y., HUANG, Z., XIA W.-L. Properties stability and biodegradation behaviours of soy protein isolate/poly(vinyl alcohol) blend films. *Polymer Degradation and Stability*, 2010, vol. 95, p. 1226–1237.
8. ZHANG, L. *Physicochemical, morphological, and adhesion properties of sodium bisulfite modified soy protein components – B. S. Thesis*. Kansas, Manhattan: Kansas State University, 2008. [citirano 20. 04. 2011]. Dostopno na svetovnem spletu: <http://krex.k-state.edu/dspace/bitstream/2097/1707/1/LuZhang2008.pdf>.
9. ZHANG, L., ZENG, M. Proteins as sources of materials. V *Monomers, Polymers and Composites from Renewable Resources*. Uredila M. N. Belgacem in A. Gandini. Oxford, Boston : Elsevier, 2008, p. 479–493.
10. SWAIN, S. N., BISWAL, S. M., NANDA, P. K., NAYAK, P. L. Biodegradable soy-based plastics: opportunities and challenges. *Journal of Polymers and the Environment*, 2004, vol. 12, p. 37.
11. RIJAVEC, T., ZUPIN, Ž. Soybean protein fibre. V *Recent Trends for Enhancing the Diversity and Quality of Soybean Products*. Uredila D. Krezhova. Rijeka : InTech. 2011, p. 501–522. Dostopno na: <www.intechopen.com>.

12. ROBSON, R.M. Silk composition, structure and properties. V *Handbook of Fibre Science and Technology*, *vol IV.* Uredila M. Lewin in E.M. Pearce. New York : Mercel Dekker, 1985, p. 649–700.
13. BOYER, R. A., ROBINETTE, C. F., ATKINSON, W. T. *Artificial fibres and manufacture thereof.* US Patent 2,377,854 (1945).
14. LI, Y. The soybean protein fibre – a healthy & comfortable fibre for the 21st century. *Fibres & Textiles in Eastern Europe*, 2004, vol. 12 (2), p. 8–9.
15. MATHUR, M., HIRA, M. Speciality fibres – I: soybean protein fibre. *Man-made Textiles in India*, 2004, vol. 32, p. 365–369.
16. BROOKS, M. M. Soya bean protein fibres – past, present and future. V *Biodegradable and sustainable fibre.* Uredil R. S. Blackburn. Cambridge : Woodhead Publishing, 2005, p. 398–440.
17. SOLARO, R., CORTI, A., CHIELLINI, E. Biodegradation of poly(vinyl alcohol) with different molecular weights and degree of hydrolysis. *Polymers for Advanced Technologies*, 2000, vol. 11, p. 873–878.
18. PREMRAJ, R. in DOBLE, M. Biodegradation of polymers. *Indian Journal of Biotechnology*, 2005, vol. 4, p. 186–193.
19. SU, J. F., YUAN, X. Y., HUANG, Z. in XIA, W. L. Properties stability and degradation behaviours of soy protein isolate/poly(vinyl alcohol) blend films. *Polymer Degradation and Stability*, 2010, vol. 95, p. 1226–1237.
20. ZEE, M. van der. Biodegradability of polymers – mechanisms and evaluation methods. V *Handbook of biodegradable polymers*. Shawbury; Shrewsbury; Shropshire : Catia Bastioli, Rapra Technology, 2005, p. 1–32.
21. SIMONČIČ, B., TOMŠIČ, B. *Biorazgradnja tekstilnih vlaken in njihova protimikrobna zaščita*. Ljubljana : Naravoslovnotehniška fakulteta, Oddelek za tekstilstvo, 2010.
22. ZUPIN, Ž., DIMITROVSKI, K. Mechanical properties of fabrics from cotton and biodegradable yarns bamboo, SPF, PLA in weft. V *Woven fabric engineering*. Uredila Polona Dobnik-Dubrovski. Rijeka: Sciyo, cop. 2010, poglavje 2, p. 25–46.
23. *Tekstilije – Ugotavljanje odpornosti tekstilij, ki vsebujejo celulozo, proti mikroorganizmom – Preskus z zemljo – 1. del: Ocena apreture zaviranja gnitja (ISO 11721-1:2001)* SIST EN ISO 11721–1.
24. BUKOŠEK, V. *Program »DINARA«: program izračuna in vrednotenja mehanskih in visokoelastičnih lastnosti vlaken iz diagrama specifična napetost/raztezek*. Ljubljana : NTF Oddelek za tekstilstvo, 1988.